dipartimento economia Marco Biagi

DEMB Working Paper Series

N. 100

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December 2016

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ISSN: 2281-440X online

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Abstract
The detection of communities of agents that interacted over time through regional innovation policies is analyzed through the application of three methodologies: Clique Percolation Method (CPM) by Palla *et al*. (2005), Infomap by Rosvall and Bergstrom (2008), and Dynamic Cluster Index analysis (DCI) by Villani *et al*. (2013). In a economic context of analysis centered on such a complex object as innovation, the three methodologies are applied to investigate different specific aspects of community organizations aimed at developing innovative activities. The investigation of relational structures (through CPM), of shared processes (through Infomap) and of integrated behaviors (through DCI analysis) allowed the identification of communities that reveal, respectively, meaningful characterizations in terms of agents' participations in specific waves of the policy, of agents' participations in projects operating in particular technological domains, and in terms of agents' institutional typologies. The case study regards the policy interventions implemented by region Tuscany (Italy) in 2000-2006 with the aim of supporting innovative network projects among local actors.

Keywords: innovation, interactive agents, Clique Percolation Method, Infomap, Dynamic Cluster Index analysis, regional policies
JEL Codes: O31, R58

A preliminary version of this working paper was presented at the Eu-SPRI Forum Early Career Researcher Conference (ECC) "Science, Innovation and the University: keys to social impact" (INGENIO PhD Days 2016), 13-15 April 2016, Valencia (Spain).

1. Innovation and interactions among agents: structures, processes and functions

As long as innovation is considered as an exogenous determinant of economic growth, it is difficult to correctly understand the processes that facilitate it. Although mainstream economic theory has depicted innovation as a unforeseen shock, new approaches to the comprehension of innovation processes have identified specific conditions that typically lead to its occurrence. Thus, with the goal of deepening the comprehension of a phenomenon whose architecture was being seen more and more as articulated and complex (although complexity is not a synonym of impossibility nor of randomness), at the beginning of the 90's new contributions (Freeman 1988; Lundvall 1988, 1992; Nelson 1988, 1993) started to investigate the role of the circulation of information and of interactions among agents (people, enterprises and institutions) in the context of the flourishing of innovative processes. While the main aim of these authors was to study the ability of national economic systems to innovate, the introduction of such an approach in the literature fostered the investigation of the interactive dynamics that characterize the rise and the development of innovation processes at a meso-level of analysis (Saxenian 1994; Breschi and Malerba 1997; Malerba and Orsenigo 1997, 2002) and at a micro-level of analysis (Lundvall 1985; Freeman 1991; Mowery and Teece 1996; Russo 2000).

An inspirational contribution for the conceptualization and the investigation of innovation was given by David Lane (Lane and Maxfield 1997, 2005; Lane 2011) who outlined a theory capable of describing the most important entities and the most important phases that characterize the formation of innovation. Far from looking for predictability, Lane's theory focuses on how the processes that led to innovations are intertwined, making some acute elements emerge. Among those that have a crucial impact on the likelihood to generate innovations in geographically defined systems, the presence of a high level of interactions among agents has been emphasized (Lane 2011). More specifically, in order to analyze the innovation prospect of agents interacting in a local economic context, three aspects deserve to be investigated: (i) *relational structures*, (ii) *shared processes* and (iii) *common functions*.

These three aspects regarding the conceptualization of 'innovative organizations' (i.e. interacting groups of agents with the capability to give rise to innovative activities) require the application of specific methodologies. Thus, in order to coherently investigate each of them, the use of three methodologies is proposed in this paper: (i) the Clique Percolation Method (CPM) by Palla *et al*. (2005); (ii) Infomap algorithm by Rosvall *et al*. (2008, 2011, 2014); (iii) the Dynamic Cluster Index analysis (DCI) by Villani, Filisetti, Benedettini, Roli, Lane and Serra (2013, 2015). I will apply these methodologies to a regional innovation policy programme. Policy implications will be discussed with regard to the design and measurement of network policies.

2. Motivations for the application of the three methodologies

The first methodology, CPM, is one of the most consolidated Social Network Analysis (SNA) methods and an unavoidable starting-point for an analysis that pursues the identification of overlapping communities of agents. Its functioning is based on the presence of adjacent k-cliques, where a k-clique is a complete subgraph made up of k nodes and where two k-cliques are intended to be adjacent if they share k-1 nodes. For

this reason, the application of CPM was aimed at detecting communities characterized by intense relational structures.
The second methodology, Infomap, is a recent and largely acclaimed method that, performing random walks over the network, allows the detection of those groups of nodes within which the simulated flow tends to circulate for long before exiting. Through the observation of the intensity with which agents were connected among each others, Infomap was applied to detect groups characterized by the capability to activate shared processes. Since common working activities necessarily involve the circulation of communications, the flow simulated by Infomap is intended as a representation of the dynamics of spreading of information over the network.
Finally, DCI methodology is a new method that, through the consideration of how agents' behaviors show levels of coordination during a considered period, allows the identification of functional subsystems thanks to the calculation of some information-theory measures (entropy, integration and mutual information). Starting from the inspiring contribute of Tononi *et al*. (1994, 1996) in the comprehension of the functioning of neurons in the brain region, DCI aims to detect groups of agents that, even if not closely connected in the network, show behavioral patterns that are far from being random. Since the presence of integration among specific neurons' activities confirmed the hypothesis that these neurons have similar functions (Tononi *et al*. 1998), the application of DCI methodology reflected the intention of investigating the presence of communities whose agents are characterized by having similar objectives and similar purposes.

3. The case study: Region Tuscany (Italy) policies in sustain of innovation

Analyses have been realized thanks to an original and unique dataset of network projects funded by the regional government of Tuscany from 2000 to 2006 (Caloffi, Rossi and Russo 2014, 2015, 2016), in the context of an entire set of public policies made up of 9 waves exclusively aimed at the financing of innovative projects. More than 1,600 economic agents participated (enterprises, universities, trade associations, service centers, KIBS, business services enterprises, etc.) and more than 160 network projects were funded (out of nearly 300 proposals). In order to participate and to receive funds agents had to develop projects in collaboration with other agents (the policies allowed exclusively the granting of funding to partnerships of agents) and so the configuration of a high number of partnerships produced an intertwined and dynamic network of interactions. Thus, the objective of this work is to investigate if agents gave rise to entities which go beyond the boundaries of the single projects and in which new architectures arose with potentiality to foster the flourishing of innovative activities. To do this, the detection of overlapping communities of agents was elaborated applying the three mentioned methodologies.

4. Three models of CPM analysis

The informational basis used for the application of CPM methodology regards the presence of connections (unweighted edges) among agents (nodes). It is very important to underline the fact that the results obtained have to do with a single specific element: the dimension of the clique that 'rolls' through the network. The definition of this parameter, that is commonly indicated with the word *k*, is crucial in the analysis and, if there are no specific theoretical reasons that could help to determine it *a priori*, represents a problematic step.

Even if in this analysis there are no theoretical references that can help in selecting specific values of *k*, it is unfeasible to elaborate a soft clustering for each possible values of it. However, looking *a posteriori* at the characteristics of all the obtained community structures in terms of (i) the dimension of the communities detected, (ii) the number of the communities detected and (iii) the degree of overlaps among the communities detected, it is possible to define three ranges of the values of *k*, within which the obtained soft clusterings have similar features[1]. The identification of different ranges of *k* has the purpose to support the process of selection of some specific values of *k* and, since three of these groups were identified, three CPM models where elaborated: the first with *k*=5 (named CPM_k05), the second with *k*=12 (named CPM_k12) and the third with *k*=18 (named CPM_k18).

5. Three models of Infomap analysis

The informational basis used for the community detection through Infomap algorithm regards the participations that agents had in common projects (weighted edges). Moreover, in order to give a better representation of the observed time dynamics, the chronological sequence of projects was used to constrain the circulation of the simulated flow (assuming second order Markov conditions). Each Infomap model is asked to detect overlapping communities and, concerning the parameter called 'teleportation probability'[2], there are no reasons to fix it at values different from 0.15. About the weight structure, weights are attributed to edges, emphasizing the number of common

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[1] The first group of partitions can be associated with values of *k* between 3 and 8. For these values there is a limited number of communities with non homogeneous dimensions. Excluding *k*=3 that can be considered as an outlier, there is a minimum of 13 communities with *k*=4 and a maximum of 21 communities with *k*=8. Moreover, even if they show a high number of connections among communities, these partitions do not represent the most overlapping situations that were found in this analysis.
The second group of partitions can be associated with values of *k* between 9 and 16. These partitions are characterized by such a high number of overlaps, that the average number of overlaps per community reaches the value of 8.44. The structures of communities that were detected are very entangled and they can only represent with difficulties what is being investigated in this work. In a network made up of 352 agents, having 32 communities with 17 of them that overlap with more than 15 groups, does not seem a plausible representation. Certainly, a situation in which the number of overlaps among communities increases so intensively, cannot be regarded with much interest in terms of a reasonable economic partition. However, there is an element that has to be investigated: the sudden convergence of minimum and maximum dimensions of communities reveals the achievement of a homogeneous condition. Something changes very quickly and for this reason the range of values of *k* between 9 and 14 deserves to be taken into account.
The third group of partitions can be associated with values of *k* between 17 and 22. In these partitions it is possible to observe that the number of communities and the average number of overlaps per community diminish, reaching values very similar to those observed in the first group. With respect to the first group, the difference that has to be underlined lies in the distribution of the dimension of communities. While in the first group of partitions the standard deviation of the communities' dimensions was around 100 units, in this group the same quantity is never higher than 5. The communities of these partitions have almost always the same dimension, and this constitutes a big difference with the first group of partitions.

[2] The teleportation probability is an Infomap parameter that represents the probability that, at each step, the simulated flow moves into nodes that are not adjacent to the node in which it is. The flow can make 'jumps' over the network during its circulation.

participations that couples of agents had. Finally, what has still remained excluded, is the Markovian order that is going to be used. Different considerations can be made about it, and the elaborated models differ from each others in terms of its setting.

5.1. Infomap model MKV1: a memoryless flow of information

The first model I propose (named *MKV1*) is a model in which the Markovian order is set equal to 1. This means that no information about the provenience of the flow is taken into account. When the flow moves through the network, at every step it faces a set of probabilities of moving in different directions that depends on (in order):

- the teleportation probability;
- the position of the flow;
- the weight structure of edges.

Simulating the propagation of a flow over the whole network without any kind of constraint (memoryless flow) is like observing the propagation of an information stream in a context where all edges are open. This is the case of a situation in which all agents maintained active their relations with all other agents they collaborated with. It is like observing the network at the end of the policy cycle, assuming that all edges have continued to be active.

5.2. Infomap models MKV2_AS and MKV2_DS: second Markov order models

The second and the third models that I developed (named MKV2_DS and MKV2_AS) are second order Markov models. This means that the direction that the simulated flow takes at every step depends also on where it was at the preceding step. The process of creation of the fake flow was implemented through the creation of trigrams. The existence of a flow among ordered groups of three agents (the trigrams) is hypothesized when one of these two conditions is satisfied:

- all three agents are involved in the same project (within project flows);
- the first agent and the last agent participated in two different projects, while the second agent participated in both of these[3] (among projects flows).

The idea behind the construction of the fake flow is that agents, only after having participated in a project, they can spread information over the network. The crucial aspect in establishing how these flows move, regards the consideration of the temporal order of the projects[4]. Since the flow represents information accumulated through the participations in projects, the first hypothesis that is accepted is that the flow could move between two projects, the first of which terminated before the end of the second[5].

[3] The second agent, that is the one that participated in two projects, becomes a ‘bridge’ between the agents uniquely involved in one of the two projects.

[4] The sense of these hypothesis is that after having finished a project, participants accumulated knowledge and so they can give rise to a flow of information.

[5] The idea is that when a project ends, participants will not have any other information from it and so every thing that was learnt in that context could be transferred into another context. Thus, since it has been decided to simulate the presence of all possible flows among projects, it follows that it is automatic to assume the existence of a flow between a terminated project and any other successive one (obviously through the presence repeated presence of at least one agent).

Underlying this hypothesis, that admits flows among projects exclusively when the project of origin terminated, there is the idea that information that circulates concerns the experience and the knowledge that accrue thanks to the complete realization of a project. On the other hand, admitting the possibility of a spreading of information before the project has terminated, has more to do with a concept of acquaintanceship, rather than accumulation of knowledge.

Both these hypotheses must be regarded with interest and both can be crucial in a process of flourishing of innovation. Thus, two models reflecting these two different hypotheses were elaborated. In the first of the two models with a second order Markov condition, the propagation of flow moving exclusively from projects that have finished is considered. The name this model is *MKV2_DS*, that stands for: Markov order 2 with Denied Simultaneity[6]. In the second of the two models with a second order Markov condition, the propagation of flow moving from projects that still have not terminated is also considered. The name of this model is *MKV2_AS,* that stands for: Markov order 2 with Admitted Simultaneity.

6. Three models of DCI analysis

At the time this work was starting, DCI analysis was a new methodology and it had never been applied to a socio-economic context of research. Since then, many steps have been taken to implement the algorithm, many evaluations have been developed and many choices have been made, in order to understand how the model could better fit a new field of application. From the perspective of this work, it is important to describe also the first attempt to apply DCI analysis to this case study. This first exploration, that presents problematic aspects, contributed dramatically to the set up of a more definite and coherent analysis. Thus, before describing the two models that have been used in the definitive application of DCI methodology, it is necessary to introduce the first process of analysis and to explain every detail of it.

6.1. DCI model 'BOOL_1'

The first process of analysis with DCI methodology was characterized by the use of boolean variables[7] to describe agents' activity over time. For this reason, this process was called 'BOOL_1'. As for all other DCI applications, in BOOL_1 are considered those 352 agents that had at least two participations in funded projects, and these agents are

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[6] The term 'simultaneity' refers to the agents' capability to generate flows of information from projects that still have not ended. If the simultaneity is admitted, it means that the agent can generate a flow between two projects in which is participating in even if they are still going on.

[7] A boolean variable takes value 0 if the agent is not active, and it takes value 1 if the agent is active. In this analysis 59 variables were elaborated, one for each identified instant in time. The activity of agents has been defined as the participation to at least one funded project.

observed in 59 different instants over time[8]. BOOL_1 was a process that represented a completely new exploration. It is important to highlight that the discovery that groups (especially in first rounds) with the highest levels of t_{ci} were groups of uninteresting actors (regarding a context of analysis of regional economic processes of innovation), led to the necessity to guide the analysis in the direction of those agents that for many reasons were considered as holders of key roles.

Thus, in the first process of analysis groups that step-by-step were identified were progressively excluded from the analysis. This way to proceed was due to the difficulty to evaluate the resulting detected groups, since every time the algorithm is run, it detects 75.000 groups of agents that can differ from each other just for the presence/absence of one agent. It is immediately clear that the detected groups are very similar among each other and so, to overcome this situation, this was the procedure that was applied:

- after the algorithm was launched, the best detected group was selected as a community;
- the detected community was skimmed from the analyzed set;
- the same analysis was iterate over the remaining agents.

This procedure, with few exceptions, continued until the set of analysis was empty. By doing so, two drawbacks emerged:

- overlappings among communities are not possible;
- t_{ci} of different communities is not comparable because of methodological aspects.

Thus, a new way to evaluate the results produced by the algorithm was needed.

6.2. DCI model 'BOOL_2'

The second process of analysis with DCI methodology, was done using the same informational basis as model BOOL_1: 352 agents and 59 boolean variables that describe the activity status (in a binary form) of agents over time, with respect to their participations in regional public policies. Considerations and reflections that emerged from the first process of analysis BOOL_1, led to the desire to elaborate another model that would be less arbitrary. The choice was to conduct a new analysis that, starting from the same initial basis as the previous one, could advance trying to overcome the perplexing aspects that emerged during the first process. Because of that, this new process is characterized by a more rigid structure that tries to furnish a more reliable support for the revealed difficulties. This new process of analysis identifies a completely new model, and it will be referred to it as 'BOOL_2'. Here the main steps (in order) that characterize the model are summarized:

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[8] Because of the fact that DCI is calculated through a comparison between entropy related measurements of the whole set and entropy based measurements of subsets, when the whole set remains equal to itself over time no useful information is added to the analysis. The permanence of the whole set in a particular state does not affect any subset's ratio between the exchange of information with the rest of the system and the internal integration. That is the reason why the crucial element that has to be considered in the construction of time data, is that the highest number of instants in time is required, but under the condition that there is a variation in the states that the whole set assumes. This fact immediately led to the consideration of the projects' starting and ending date as points of reference in time dimension. Working on all available dates of starting and of ending of funded projects, it was possible to define 52 instants over time, where an instant corresponds to a daily date. In addition, it was possible to add 7 new instants in time working on non funded projects, allowing a final extension of the time dimension to 59 daily dates.

- 30 runs of the algorithm in every round and single final ranking of all analyzed masks;
- selection of the mask with the highest t_{ci} value at the end of every round;
- progressive skimming, round after round, of the mask selected at the end of the previous round;
- iteration of the analysis over several rounds;
- stopping of the skimming procedure after the substantial loss of agents that the researcher retains must not be excluded;
- hierarchical agglomerative cluster analysis of 12.500 masks with the highest t_{ci} value: simple matching as similarity criterion and complete linkage as agglomerative method.
- dendrogram cut with respect to (i) the length of branches, to (ii) the identification of clusters with a good degree of diversity among them, and to (iii) the involvement of a good number of agents;
- in every cluster, selection of the mask with the most significant score of DCI, as the representative mask of that cluster.

6.3. DCI model '∂LoA'

After exploring the process of analysis BOOL_1 the decision was taken to experiment other models with an ameliorated structure in terms of methodology. This is what has been done with model BOOL_2 and with another process of analysis which was called '∂LoA'. The acronym has to be read in this way: '∂' stands for 'variations' and 'LoA' stands for 'Levels of Activity'. Instead of considering boolean variables, here variables were used that express the relation between the number of projects in which the agent was active in a specific instant, and number of projects in which the agent was active in the previous instant[9]. What was done was a further step in the characterization of the activity status: the elaboration of this new series of variables allows the real introduction of the time dimension, while with boolean variables the time was considered only through the necessary identification of instants in which to observe agents, in this new model the activity of agents is described in terms of evolution. All features of model ∂LoA, except the nature of variables, are the same as model BOOL_2.

7. Main results and conclusions

First of all, the application of the three different models of CPM allowed the detection of communities that the higher the values of *k*, the higher their characterization in terms of

[9] Thus, 58 variables were elaborated in this way:

- if the agent has a number of active projects higher than the number of projects the agent was participating in, in the previous instant, the corresponding variable assumes value 3;
- if the agent has a number of active projects equal to the number of projects the agent was participating in, in the previous instant, and the number is greater than zero, the corresponding variable assumes value 2;
- if the agent has a number of active projects lower than the number of projects the agent was participating in, in the previous instant, and the number is greater than zero the corresponding variable assumes value 1;
- if the agent is participating in no funded projects, it has to be considered inactive and so the corresponding variable assumes value 0.

participations in specific waves. The observation of meaningful contingency tables allowed me to see how, especially in the model CPM_k18, every detected group is characterized by a significant number of participations in projects developed in one of the 9 waves. Thus, having applied CPM to study the presence of communities characterized by intense relational structures, it seems to me coherent that the detected groups are made up of agents that have significant participations of this kind. The waves and, before them, the policies' implementation, were crucial to determine the shape of the agents' connective framework. Through the definition of specific domains of interventions and through the imposition of different constraints to the agents' participations, the policies that were implemented over time necessarily affected the construction of the network relations.

Infomap models also show results in line with the purpose for which this methodology was applied. The three community structures detected are made up of communities characterized by agents' participations in projects related to specific technological domains. A similarity emerged between the communities identified, especially those detected by imposing restrictions on the circulation of the flows, and the partnerships that during the policies were realized. Infomap methodology, which was applied to investigate groups of agents characterized by the capability to share working processes, allowed me to detect communities which seem to reflect the participations in the most important common activities observed in the context of the cycle of policies: the projects.

Finally, the application of DCI algorithm, also revealed results that deserve attention. The community structures that were detected were analyzed through the computation of meaningful contingency tables. While with the preceding methodologies characterizations regarding the agents' participations emerged, with this analysis the communities detected seem to be related to a different kind of feature, the typology of the agents involved. In particular, model '∂LoA', the one in which the method was applied over the most refined informational basis and in which I introduced a procedure of cluster analysis of the large quantity of masks detected by the algorithm, allowed the identification of a community structure in which, on one hand, KIBS and enterprises, and on the other, KIBS and enterprises and universities, determine two distinct groups of communities. Since this methodology originated to detect functional groups (Tononi *et al*. 1994), the emergence of the salience of the typology of agents seems to underline that similar agents have similar finalities. The presence of integrated activities (that are what DCI algorithm investigates) can be reasonably related to the presence of similar typologies of economic institutions, since it can be said that the specific nature of agents necessarily influences their functions and these, in turn, determine specific behavioral patterns.

This is what the application of the different methodologies produced and what their results suggested. This work has attempted to start out on possible paths to analyze a complex theme, that of innovative communities, and the results have to be investigated more deeply. Nevertheless, some elements have emerged and they seem to suggest that these analyses were coherent with the intent to which they were applied. Since there are no specific examples in the literature that testify to the appropriacy of the application of these methodologies to the investigation of innovative dynamics in a socio-economic context, there was no guarantee that the described characterizations would be found. Even if further research is needed in order to better investigate the dynamic interactions of agents, the analyses allowed the detection of meaningful communities. The results that emerge are in line with what was investigated and this represents the confirmation that appropriate methodologies were used and that their application was coherent.

8. Further considerations: the coexistence of relational structures, of shared processes and of common functions

Following the considered literature (Lane and Maxfield 1997, 2005; Lane 2011), it is possible to assert that groups of agents develop the capability to produce innovation if the three investigated aspects are simultaneously present (*relational structures*, *shared processes* and *common functions*). Having investigated them separately, the final point of this work is to understand if there are agents that are simultaneously grouped together by CPM, and by Infomap and by DCI analysis. To do this, I calculated the intersections generated by all possible combinations of three communities as follows:

- the first community is one of the communities detected with CPM;
- the second one is one of the communities detected with Infomap;
- the third one is one of the communities detected with DCI.

After having computed for each combination the corresponding Jaccard index[10] (i.e. the ratio between the number of agents that are present in the intersection and the number of agents that are present in the union set), to every agent was attributed the highest ratio among those referred to intersections in which is present. Considering the elaboration of three probit models (with robust standard errors) were the independent variables describe different kinds of participations in the policy cycle 2007-2013 (the one following 2000-2006 policies), the coefficient of the independent variable describing the highest Jaccard ratio becomes significant and positive only when the dependent variable is a dummy that assumes value 1 if the agent has signed at least one collaboration agreement (in the period 2007-2013). Since collaboration agreement has to be considered the type of relation most oriented to the purpose to develop innovative initiatives, the presence of the agent in an 'intense' intersection (a combination of three communities in which, with respect of the union set, there are many agents that are always grouped together under the three perspectives adopted) seems to have a significant role in the continuation of innovative activities over time.

The study of the intensity of the overlaps among communities detected with the three methodologies makes possible to conclude that the simultaneous presence of relational structures, of shared processes and of common functions has to be regarded as a relevant element in the identification of those agents that tends to develop innovative activities. With regard to policy implications, the most important aspect is that the identification of the key groups of agents can be done without relying on the agents' technological or

[10] It is appropriate to consider the ratio between intersection and union set, rather than for example considering the dimension of the intersection, because it has not to be forgotten that the unit of analysis has to be retained the 'community'. Taking only a part of it does not guarantee that this portion would have been detected as a community. A subset of the agents that are in a specific 'organization' do not necessarily determine another 'organization'. Thus, the most appropriate index to which it is possible to think to, measures the number of those agents that are simultaneously grouped together in communities reflecting each of them one of the different considered aspects (*relational structures*, *shared processes* and *common functions*), in terms of the overall number of agents that are involved in the same communities. This is exactly how the Jaccard index is calculated.

economic classification, but considering agents' interactions. Policy interventions should be implemented taking care of the evaluation of the results reached by agents, as well as of the observed ongoing dynamics.

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