Evolution and Dynamics of Networks in 'Regional Innovation Systems' (RIS)

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I. Introduction

In 1992 Cooke introduced the notion of "Regional Innovation Systems" (RIS) (Cooke 1992). The notion synthesizes two strands of research: the discussion about 'National Innovation Systems' (NIS) and empirical studies on regional development dynamics.
The research about NIS was founded by Freeman (1987) and Lundvall (1988) and rapidly gained acceptance (e.g. McElvey, 1991; Nelson 1993; Metcalfe 1995). A lot of studies specified the notion of NIS since then (e.g. Freemann 1995; Lundvall et al 2002; Lundvall 2007). The background of the seminal work of Freeman and Lundvall was a new perspective on innovation. At that time, Kline/Rosenberg (1986) had introduced their model of a "chain linked process of innovation". The concept of NIS goes beyond this model in that it takes into consideration the influences of space, common norms, institutions and cooperation on the innovation process. The characteristics of these aspects together with the ability of the firms to absorb and transform knowledge constitute a NIS.
During the 1980s seminal studies about the fundamentals of regional development have been done, including the investigation of regional innovative capacities (e.g in the Emilia Romagna (Italy), Baden-Württemberg (Germany) and Wales (England)) (Cf. Sabel et al 1989; Cooke 1991, Cooke/Morgan 1990, 1991). Those studies gave evidence that not only the national level is of importance for the analysis of innovation systems but also the regional level. Particularly as regards to common norms and culture, but also as regards to regional policy institutions a more 'locally' oriented perspective was called for.
Hence, following Asheim/Isaksen (2002, p. 83) RIS can be defined as "….places where close inter-firm communications, social structures, and the institutional environment may stimulate socially and territorially embedded collective learning and continuous innovation". This definition is backed by the observation that agents in a region can intensify their relations due to 'proximity' in terms of space and social as well as technological compatibility. This proximity is promoted (and in some cases even initiated) by different forms of institutions ranging from 'hard' infrastructure and regulation to 'soft' mental models and trust. In comparing RIS with regions where no such an integration of different resources takes place researchers claim that making use of regional proximity is a source of additional generation and diffusion of knowledge, a faster learning process and an increase of innovations. Consequently the selective formation of RIS is used as an explanation for the significant differences in the development of regions in terms of Gross Domestic Product (GDP) and employment.
For rendering plausible these allegations about the additional yields of RIS it is not sufficient to relate the regional boundary conditions (e.g. in terms of political regulations and knowledge transfer from universities) on one side and the outcome (e.g. in terms of innovations, GDP and employment) on the other side. Rather it is necessary to analyse the internal processes in RIS more closely. *Firstly*, innovations – representing a specific mode of action – are neither 'coming out of the blue' nor are they automatically generated by competitive market conditions. This mode of action requires agents willing to innovate and promoting the corresponding activities (thereby leaving other modes of actions). *Secondly*, attributing the binary distinction 'innovation' vs. 'not innovation' to these agents is too

simplistic in the context of RIS. As regards to the regional effect mere imitations are different from innovations, incremental innovations have to be distinguished from radical innovations, and individual innovations differ from cooperative innovations. *Thirdly*, multiple coordination mechanisms interact in the formation of RIS: market relations are supplemented as well as structured by institutional relations and network relations are overarching both. Hence, analysing RIS more closely necessitates to take into account the involved agents, their different modes of action, and their embeddedness in different coordination mechanisms.

Due to the complexity of the subject matter and to the dominant aggregated perspective (meso-level) of the research about RIS the aforementioned topics are not yet systematically taken into account. A starting point for such a research endeavour are simulation studies about the importance of proximity and networking for innovations in a regional context using an agent based perspective (cf. Brenner 2001; Gilbert et al. 2001; Zhang 2003). The present elaboration follows this strand of research but tries to be more specific in terms of integrating the agent-based perspective and regional network analysis.

Taking agents as the basic unit of a RIS it seems necessary to pick up modern insights of cognitive psychology (cf. Anderson 2000) for explaining the agent's repertory of the ways to act as well as the conditions for selecting a specific mode of action in a given situation (in terms of internal and external states). Even if there is a common understanding of what is going on within a given mode of action (like routine, imitation, innovation etc.) it is crucial for a behavioral foundation of RIS to focus the triggering conditions for the different modes of action (including innovation and networking). Hence, we use a multi-mode approach to human action (cf. Camerer 2005; Svenson 1996; Louis/Sutton 1991) and systematize it by incorporating insights from the Ajzen school as well as the Carnegie school of behavioral research.

This agent-based perspective implies a specific approach to networks as a part of activities in RIS. Contrary to the usual top down perspective focussing global network properties (like efficiency, stability etc.) a bottom up perspective is required taking into account the agent's motivations, capabilities and constraints to act in a network context.[1] Due to the different coordinating mechanisms operating at the same time in a RIS it seems appropriate not to subsume all relations in that system under a broad notion of network but to reserve this notion for a specific way to coordinate activities lying between market coordination on one side and hierarchical inner firm coordination on the other side (cf. Ménard 2004). Taking into account the 'distance' (in spatial, social, cultural, technological or cognitive terms) necessarily inherent in market operations (cf. Cowan 2004) as well as the 'threat' (again in spatial, social, cultural, technological or cognitive terms) of hierarchical relations (cf. Miller 1992), networks are creating a mid-term proximity for which the region is the generic place.[2]

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[1] Hence, neither large 'scale-free' networks (Barabasi 2003) nor the usual 'small-world' network approach (Watts 1999) is appropriate for the perspective chosen here: for different reasons they are not related to the micro-level of economic agents.

[2] Cowan (2004) identifies three (interrelated) drivers towards a network-type of interaction and coordination: (i)'Imperfectness' of markets as regards to product- and person-related background information; (ii)outsourcing of firm activities bringing about new coordination requirements and (iii)transfer of knowledge as a specific part of economic interaction.

Integrating the agent-based perspective and regional network analysis then has a two-fold meaning: on one side the microeconomic conditions for regional networking (constraints as well as possibilities) have to be specified; on the other side the feedback from ongoing regional networks to the level of individual activity has to be included in such an analysis. In pursuing such a perspective the next *section II* addresses the required conceptual foundations: in section II.1 layers of RIS in terms of modes of action and institutional embeddedness are distinguished; in section II.2 the factors determining the behavior of agents and correspondingly their willingness to contribute to a RIS are analysed more closely. These conceptual foundations (as well as additional empirical observations) are the background for the architecture of the simulation model which is presented in *section III*. The results of this simulation model are dealt with in *section IV* especially focussing the network dynamics being the core of a RIS. Some conclusions are discussed in *section V*.

II. Conceptual foundations

II.1 A multi-layer concept of RIS

Taking into consideration that RIS have a specific environment and a differentiated internal structure, multiple layers can be distinguished according to the internal mode of action of agents and their institutional embeddedness.[3] Every additional layer adds at least one additional type of relation to the relations already existing (cf. fig. 1)[4]. Switching between layers then implies a modification of the internal states of the agents being the entity promoting the different levels of activities. This modification may include a difference in the orientation towards other agents as well as a difference in mobilizing capabilities to act.

The *first* outer layer – actually the environment of RIS – is given by political (legal), geographical and cultural attributes determining the interaction of agents. Apart from this common denominator the agents are only loosely coupled (e.g. by regional markets and regional political processes). The agents in this layer are not (yet) engaged in a novelty creating activity (innovation or imitation). The *second* layer – the first layer of RIS proper – is defined by additional institutional structures being relevant for those agents who are willing to create novelties (either by imitating or by innovating). The basis for these additional institutional components are declarations or commitments of a subset of agents (firms, politicians and scientists) to promote a subpart of the region leading to some kind of supplementary structures (e.g. regional manager, regular meetings etc.). Correspondingly, the agents on this layer are internally in a mode of action aiming to create a novelty (innovation

[3] In the analysis of RIS the (multi-)layer concept normally is used for grasping the relations between functionally different groups and institutions like firms, universities and political administration (cf. Brazcyk at al. 2004; Etzkowitz/Leydesdorff 2000). In the present study layers are characterized by different modes of activities of the same groups.

[4] The relations which are important for RIS are: market relations, institutional relations, knowledge relations and – most important – network relations.

or imitation).[5] Furthermore having a strong willingness to innovate is a necessary (but not sufficient) condition for collaboration and cooperation in terms of innovation. Agents being on this layer have to figure out (at least potentially) the appropriate interests in the knowledge of others as well as the requirements for institutional settings dealing with transaction costs and overcoming opportunism in the context of networking. If the necessary conditions for such a cooperation are given the agents start to build up trust against each other, by this reinforcing the process of collaboration and cooperation. Hence, the *third* layer – the core of RIS proper – is given by those agents who actually decide to cooperate in searching for and implementing innovations (they are internally in the cooperative innovation mode). In this layer there is an agreement about the goals pursued by innovative activities of different agents and the resources dedicated to this goal followed by processes to implement this agreement. Stabilizing trust between cooperating agents is a crucial factor for the success of these processes, i.e. its prosecution until all possible comparative advantages of cooperation (due to transferring specific knowledge, realizing economies of scale and scope, and implementing the division of tasks and parallelism in research activities) are exhausted. The existence of institutions stabilizing trust will increase the probability of success for these cooperation processes.

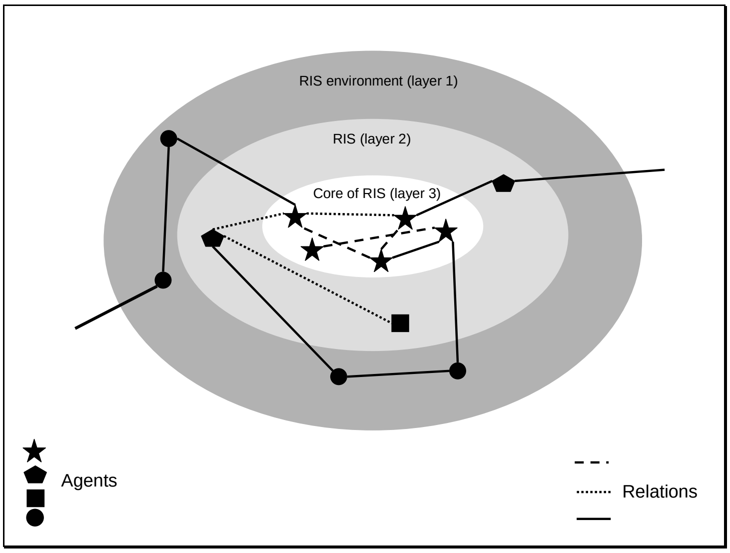

Fig. 1: 'Onion concept' of RIS

Taking the perspective of a single agent he/she either remains on a given layer or he is switches between different layers according to the institutional embeddedness and to the mode of action he is pursuing. The RIS as a whole and its dynamics is specified by the frequency of the agents in the different layers over a longer time span.

The difference between the three layers of RIS can be further specified in terms of the respective knowledge dynamics as well as the institutional dynamics. The *knowledge*

[5] As regards to the distance to the core of RIS (cf. below) this layer can be further differentiated in two subparts, one consisting of agents with moderate willingness to create novelties (imitation) and another with agents having a stronger willingness to create novelties in terms of looking for innovations proper.

dynamics being a result as well as a condition for the agent's switching between the different layers can be characterized by referring to the different nature of knowledge and the various ways it comes into existence from the agent's perspective. Here, *firstly* a distinction is made between general knowledge which is more or less public and specific knowledge which is accessible at a cost. *Secondly*, a distinction is made between virtual and real knowledge, i.e. between knowing that there is something to know and actually knowing something.

On layer 1 nothing else but a constitution of virtual general knowledge about the region happens. Agents in a region are endowed with information about their legal and political boundary conditions as well as about the regional associations, public and semi-public institutions in the region.

On layer 2 the establishment of additional regional institutions is tantamount to the (partial) transformation of virtual general knowledge into real general knowledge by way of a simple knowledge transfer. This transfer takes place on regional meetings, within regional associations and may be induced by political programs. Crucial for the knowledge transfer on layer 2 is an agreement on how to proceed in the endeavour to cooperate. Hence, to homogenize the procedural knowledge to a certain degree is another condition for success on this level. On the other side it seems necessary to maintain some heterogeneity of the declarative knowledge as a basis for the division of research activity between different agents on level 2: this establishes one of the comparative advantages over research done by isolated agents. Correspondingly the beginning of the communication between different regional agents (or groups of agents) leads to a (virtual) formation of specific knowledge relevant for the different domains in the regional context.[6]

Finally on layer 3 the transfer of common knowledge is continued and accompanied by a (partial) transfer of specific knowledge. Both takes place within the cooperation formed for the sake of innovation. Private declarative knowledge is selectively revealed between cooperating partners without becoming public knowledge. The heterogeneity of the declarative knowledge between cooperating agents is one important source for the propensity to cooperate. Revealing (at least partly) this knowledge in the process of cooperation is therefore at the same time eroding (at least partly) the cooperation.

For the *institutional dynamics* on the different layers (being also – like knowledge – cause and effect of the RIS-process at the same time but more influenced by exogenous political and cultural factors) of RIS two attributes (and the respective attribute's expression) seem to be important (cf. Quéré/Ravix 2003):

- the difference between 'hard' (technological, legal) and 'soft' (cognitive, social, cultural) institutions and
- the difference between a genesis of institutions by design and by self organization.

Going from level 1 to level 3 there is an increasing importance of soft institutions. On level 1 and especially on level 2 legal and political regulations as well as infrastructure are necessary initial conditions for any kind of cooperation procedures. These auxiliary instruments are required for overcoming regional inertia and routines and for establishing a critical mass for

[6] The main problem for low developed regions in term of knowledge is a lack of declarative knowledge (about technological fields, market domains and other regional agents). Hence, the transfer of declarative knowledge is crucial for these regions.

the RIS-dynamics. But for level-3-activities this is not sufficient: a self-enforcing trust building process strongly depends on soft institutions like shared visions and goals as well as mechanisms for punishing defecting agents.

Hard institutions are often designed by political actors and – due to lack of knowledge of their designers – not necessarily appropriate for the needs of their respective target groups. Hence, their binding function for these groups requires a self organized adaptation process of agents as well as of institutions (e.g. by exit and entry of agents and/or a modification of the institutional design). These adaptation processes are necessary for establishing coordination procedures in which these – adapted – hard institutions are accomplished by soft institutions.[7]

In the following only the internal processes of the agents on the different layers are conceptualized more closely.

II.2 Behavioral foundation of agent's mode of action on the different layers of RIS

The behavioral foundation for agent's mode of action on the different layers of RIS is elaborated in two steps: (i)In the first step we are looking for a behavioral foundation for creating novelties comprising activities different from routine and choice. Here we differentiate between the behavioral elements leading to innovation and those elements leading to imitation. (ii)In the second step we are investigating more closely the behavioral elements in favor of innovation and by drawing on additional circumstances we distinguish further between a behavioral foundation for a cooperative and an isolated way to innovate. Step (i) is backed by referring to two different concepts of action being synthesized for the given context. Step (ii) is done by specifying different conditions for the emergence and proceeding of innovation networks from a micro-perspective.

II.2.1 Synthesizing the Ajzen- and the Carnegie-approach

In the given context of RIS there are two requirements for the behavioral explanation: *Firstly*, the different modes of action specific for the different layers of RIS (routine, imitation and innovation) should be part of the explanandum. *Secondly*, this explanation should be empirically meaningful. Unfortunately there is no concept in the behavioral scientific literature fulfilling simultaneously these two requirements.[8] Therefore we synthesize two well-known behavioral approaches each of which has been applied to empirical problems and was used to explain more than one mode of action.

The focus of the *approach of Ajzen* is to explain intentional activities, i.e. activities resulting from a conscious plan to do something. According to this approach, this plan (intention) is influenced by three different cognitive factors (cf. Ajzen 1991, pp 181): (i) the attitude of the agent towards the attributes of the planned activity itself, (ii) the appropriateness of this activity for the social norms the agent is pursuing and finally (iii) the agent's ability to control the intended activity. This implies that the agent tries to anticipate the salient attributes of the

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[7] The dynamics of RIS (i.e. their 'paths') differ according to the degree in which their institutions are dominated by hard institutions and according to the amount these institutions are simply designed or accomplished (or even dominated) by self organized processes.

[8] Attempts in this direction are: Jager 2000; Fagiolo/Dosi 2003; Beckenbach 2004; Briegel 2006. Our suggestion is in the tradition of this research at the intersection of economics and psychology.

activity under consideration, that he is aware of norms he wants to follow (as well as the persons or groups representing these norms) and that he has an idea about his ability to control the intended activity. All these circumstances are valued by the agent and – in the case of multiple arguments – aggregated for each factor. Hence, for each of the factors (i)-(iii) there exists a subjective weight, influencing the overall intensity to pursue an intended activity.

From an economic perspective this approach can be assessed in a twofold manner: On one side it contains the essential features of an economic approach in that it combines goals (attitudes) and constraints/endowments (abilities to control) for explaining activities. On the other side this framework is broader than the economic standard approach to decisions in that it includes a subjective perception of social embeddedness (in terms of reference groups, norms etc.) as a core element for intentional activities. This approach is also different from a game theoretic treatment of interaction patterns in that it is not bound to any type of common knowledge assumptions and well defined strategies.

In the context of explaining agent's activities in RIS, the *first* shortcoming of this approach is the exclusion of dynamics. Even if Ajzen principally concedes that the experience of past behavior influences the initial conditions (in terms of subjective attitudes, subjective norms and subjective control beliefs) for explaining present behavior (cf. Ajzen 1991, 203) it is not clear at all how this influence takes place. The *second* shortcoming of the Ajzen approach in the given context is the neglect of other modes of action: in focusing the deliberative procedures leading to an intention, this approach deals exclusively with (a component of) decision processes. Neither circumventing intentions by automatic processes nor the search for new options of activity are explicitly part of this framework. Nevertheless attitudes, norms and control still seem to play a role when these other modes of actions are selected. So it appears to be worthwhile to integrate these modes of actions in the given framework.

Obviously there is only a narrow scope for integrating modes of action based on automaticity into the Ajzen approach. Ajzen himself (1991, 203) suggested that in the case of a very low level of subjective control (few elements of control with a low influence on behavior) intentions do not determine behavior. Rather, in this case there is a direct influence of the strong constraints on the resulting behavior. This kind of automaticity urged by the situation-specific circumstances is different from a 'learned' automaticity. The latter takes place if the situation remains rather similar for a longer time and a specific way to act proves to be rather successful in this situation (cf. Verplanken/Aarts 1999, pp 104).[9] Then the perception of situational cues seems to be sufficient for performing the well known activity. Implementing an intention by consciously selecting attributes of action, reference persons and assessing control abilities is dispensable in such a case. Rather, what takes place here is an unconscious activation of schemata or scripts stored in the long term memory. This kind of learned automaticity (different from urged automaticity mentioned above) is at the core of what usually is called 'habit' or 'routine'.[10]

[9] To act in a manner which conforms to the requirement of the situation can be a result of previously planned behavior; but it can also be derived from other types of activity as e.g. teaching.

[10] 'Habit' is the notion used in sociology and is meant to include a wide range of social and cultural explanantia; 'routine' is the notion used in economics and is more focused on explanantia inherent in the activity under consideration.

The *Carnegie-approach* is important in two respects: *Firstly*, this approach sheds light on two usually neglected modes of decision making: routines and search. Furthermore the decision units (especially firms) are not conceptualized as a consistent unit but rather as entities with internal conflicts being moderated in different ways (cf. Cyert/March 1992, pp 214, pp 229). A common denominator of these features of such a decision unit is the restriction of rationality i.e. of perceiving information as well as of the ability to transform this information into activity. Therefore a specification of the bounded rational way to settle and use goals as well as capacities by constituting an aspiration level, by following satisficing behavior, and by varying organizational slack is a *second* reason for referring to this approach.

Originally the *aspiration level* has been conceptualized in psychological field theory backed by observations about the context-dependence of the expected result of an activity and about the role of these expectations for future activities. In its economic adaptation the core idea behind the aspiration level is to internally fix a level of goal attainment which is related to past experience and/or to the observable experience of other agents being in a similar situation (cf. Cyert/March 1992, 162, 172).[11] Generally, the divergence between the aspiration level and the actual performance level is seen as a source for modifications in behavior. This is due to an evaluation according to which a negative discrepancy (performance level is lower than aspiration level) leads to the internal state of dissatisfaction whereas a positive discrepancy (performance level is higher than aspiration level) leads to an increase of ambition.

Orienting behavior towards such an aspiration level then defines *satisficing* instead of optimizing in goal attainment. Hence, the aspiration level gives a cue for dealing with bounded rationality: "Actually satisficing is less a decision rule than a search rule. It specifies the conditions under which search is triggered or stopped, and it directs search to areas of failure."(March 1994, 27) A negative discrepancy triggers a different mode of action in terms of information gathering and risk taking (cf. Cyert/March 1992, 228).[12]

The aspiration level as well as the satisficing goal attainment do not take into account the endowment of agents (in terms of knowledge, finance and time) and their corresponding capacities to act. Given the (fast) dynamics of the endeavors to meet the aspiration level and the statics (or slow dynamics) of these endowments there is a varying surplus in the capacity to act. This surplus is called '*slack*'. If this slack is large, it is seen as an additional source for novelty generating procedures because then constraints are loose giving room for playful experimentation. Contrary to the "failure-induced" search, this kind of search is "success-induced" (March 1994, 31; cf. Cyert/March 1992, pp 188; March/Simon 1993, pp 203).[13]

This success-induced search can be specified on the level of the individual as well as on the level of organizations (firms). The corresponding individual trait is curiosity as a search for

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[11] In terms of the concept of Ajzen the aspiration level has to be classified as a norm because it indicates a social interaction leading to an 'appropriate' level of goal attainment.

[12] Basically the notions of aspiration level as well as satisficing are related to the individual. In organizations like firms the level of goal attainment may be group specific and therefore be a source for a conflict. Managing this conflict is then a boundary condition for the pursuit of the original goal (cf. March/Simon 1993, pp 132; Simon 1997, pp159).

[13] Similar to the approach of Ajzen the endowment of the agent (and the correlating control capacity) is taken into account here. The difference to this approach is given by the assumption that the amount of control capacity does not simply determine an intention to act but rather a specific way to act: e.g. the switch to searching behavior.

new information, new knowledge and new experience for its own sake.[14] Recent research in this field reveals that curiosity is not simply a genetically programmed drive (activated in a crude stimulus response context)[15] but rather has cognitive sources either in searching for congruity and sense making or in practicing idle competences (cf. Loewenstein 1994, pp 80). Hence, curiosity is in the neighborhood of creativity and intimately related to the above mentioned phenomenon of slack.

On the level of firms, the slack is a necessary implication of the organizational 'coordination failure'. Given an organization consisting of a multitude of agents and resources, bounded rationality as well as opportunism will play a role in the coordination of these organizational elements. "When the presence of slack relaxes coordination and control pressures, decision makers are free to pursue idiosyncratic local preferences."(cf. March 1994, 31; Cyert/March 1992, pp 41) This will release a search for novelties on the different levels of the firm because it opens up possibilities for the different organizational departments to strengthen their relative position. The harmonizing of these different (potentially) innovative activities will be a central task for the strategic management.

For the *behavioral synthesis* at stake here the architecture of the Ajzen approach is used as the basic heuristics. This is due to the broader scope of this approach and to its greater flexibility. But *firstly* the factors used by Ajzen have to be specified for the domain of a firm in a competitive market economy and for the given context of explaining the dynamics of regional innovation. Curiosity, risk orientation and expectations about the properties of an option are taken into account as personal (or organizational) attitudes in the context of market and firms and are accomplished by including goals as an important feature of economic actors. Aspirations in terms of different economic goals are specified as the relevant 'norms'. The control component is derived from the usual elements of economic endowment (knowledge, finance and time). *Secondly*: these factors are not used for explaining a specific activity (or intention to do that activity); rather, according to the necessary behavioral enhancement, they are used for explaining the selection of the mode of action[16] and hence, for explaining one source of the dynamics between the different layers of a RIS (cf. Fig 2).

[14] In the Carnegie-approach curiosity and the corresponding exploration drive is dealt with as a component of the risk attitude. Apart from this curiosity component the risk attitude is seen to consist of a personal trait and risk taking depending on the level aspiration attainment (cf. Cyert/March 1992, pp 227-8; March 1994, pp 35-55).

[15] This notion of curiosity is related to a part of the work of Berlyne and was 'imported' into economics by Scitovsky (1976).

[16] Cf. Svenson 1990; Louis/Sutton 1991 and Jager 2000 for such a multi-mode concept of human action.

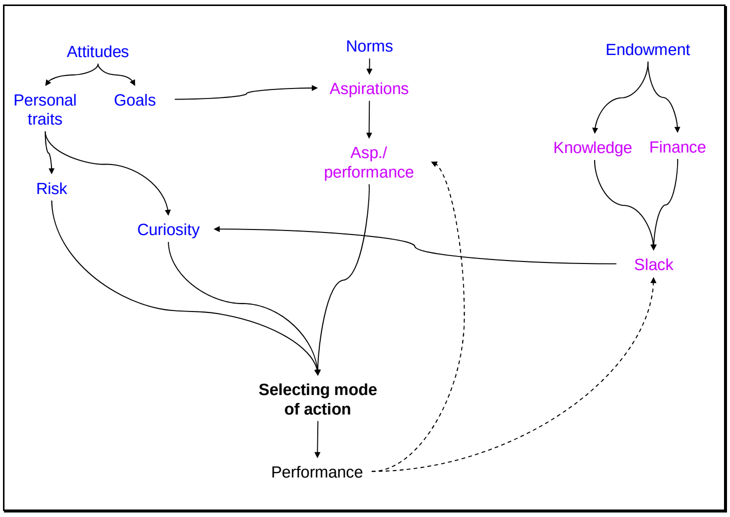

Fig. 2: Causal chain diagram for selecting mode of action

Integrating aspirations and slack in this framework allows for dealing with the behavioral dichotomy in terms of switching between search and routines. According to the context under investigation, here the search mode is further differentiated in a twofold manner: a distinction is made between a search for novelties already practiced by others (imitation) and novelties which are created by the searching agent (innovation).[17] These different modes compete for being activated by the agent due to endogenously generated forces. Activating imitation necessitates overriding the 'default mode' of routine. Practicing innovation requires higher innovation pressure to overcome the lower pressure towards mere imitation.

II.2.2 Microeconomic conditions for innovation networks

In the previous section we specified the behavioral conditions or the willingness of the agent to innovate. What has not dealt with is the question, whether, and if so why, agents choose to conduct their innovations in a collaborative manner. More precisely, the reasons why agents are moving to and from the core of the RIS are not explained. This moving as well as the collaborative innovation at the core constitute the dynamics of the RIS. In the following, we will take into consideration the network aspect of RIS and distinguish two interdependent levels of analysis: the morphology of the network and the states of the agents involved in network activities.

II.2.2.1 'Social Network Analysis' (SNA)

Although networks are undoubtedly a central feature of RIS, the respective research usually does not comprise the network morphology and, accordingly, not the feedbacks between states of agents and the network as a whole. However, recently two aspects have been investigated: the morphology of patent networks (Breschi/Lissoni 2004; Cantner/Graf 2006) on one side and the specific contents of the relationship between agents involved in an innovation network, namely the role of trust and knowledge transfer (Nooteboom 2004; 2006; Daskalakis/Monz 2006 cf section II.1 above) on the other side. Both research fields lack of a

[17] It is assumed that slack (and the curiosity derived therefrom) is only relevant in the case of innovations and that the expected costs of imitations are lower than the expected costs of innovation.

unified perspective: whereas the former deals with the multiple contents of network relations, the latter is less concerned with the morphology of the network.[18] The common denominator of both fields of research is the social network analysis (SNA). Hence, it is worthwhile to take a closer look at the SNA and the options this paradigm might provide for the analysis of innovation networks.

The SNA provides a formal method to analyse the morphology of networks and the impacts it has on the network's performance. The main thesis of the SNA is that an agent is embedded in a social environment and is influenced by this. Agents (either individuals or organisations) are connected to other agents in their social environment by interaction. These connections between the agents are called 'relational ties', the agents themselves are called 'nodes'. The main focus of the SNA lays on the analysis of the structure of these ties, especially on the pattern and/or regularities of these structures (Wassermann/Faust 2007, 3). Besides the structure, the SNA is also concerned with the contents of ties which might be, for example, biological elements, material resources, information, knowledge or trust.

Within the SNA, a basic distinction is made between an analysis of individual agent networks, especially ego-centric networks, the analysis of sub-groups within networks and the investigation of networks as a whole (e.g. Wassermann/Faust 2007; Scott 2005). The formal tools provided by the SNA differentiate between all three levels. Relevant measurements are, for example: centrality, cluster, cohesion, density, (mean) degree, multiplexity, path distance as well as value and direction of ties (cf. Wassermann/Faust 2007).

There are several possibilities to apply social network analysis to the analysis of RIS. As regards to the simulation model (section III) four measures are considered more closely: (i) multiplexity, (ii)values of graphs, (iii) direction of ties and (iv) mean degree.

(i) *Multiplexity* refers to the circumstance that between two nodes (n_i, n_j) there might be more then one tie (Wassermann/Faust 2007, pp 73). For example, if two agents at the core of the RIS are engaged in mutual knowledge transfer and if this transfer is based on mutual trust, then one tie $n_i \xleftrightarrow{k} n_j$ reflects the knowledge (k) transferred and a second tie $n_i \xleftrightarrow{tr} n_j$ contains trust (tr). Multiplexity can be measured by simply counting the number of different ties between two agents.

(ii) The *value* of a tie describes the frequency and/or intensity of the interaction (Wassermann/Faust 2007, pp140). With regard to the relationship $n_i \xleftrightarrow{k} n_j$, for example, the value ν_k is measured in terms of knowledge-units being transferred and/or in terms of frequency of interaction. Accordingly the value of trust ties represents the level of trust. In case of multiplexity, the values of the respective ties are summed up.

(iii) For both measurements, the multiplexity and the value of ties, it is reasonable to distinguish between *undirected* and *directed ties*. The two measures introduced above are related to undirected ties. They give no information about differences in case the ties are decomposed, e.g. by analysing the amount of knowledge given from n_i to n_j ($n_i \xrightarrow{k} n_j$) and vice versa ($n_j \xrightarrow{k} n_i$). Those differences are measured by directed ties. For example if n_i is giving more knowledge to n_j than n_i receives from n_j then the value of the ties is different with $\nu_{ijk} > \nu_{jik}$. Different amounts of trust between n_i and n_j can be formalized accordingly.

[18] An exception is given by Kauffeld-Monz/Fritsch 2007.

(iv) The *degree* measures the number of ties with which one agent is connected to others. The minimum degree (d) is 0, if an agent has no connection; the maximum is given with d=g-1 (g being the number of nodes). The mean degree of a network comprises the ratio of the number of actual ties between the agents and the number of nodes. Thus, the mean degree $(\bar{d})$ is given by $\bar{d} = \frac{\sum_{i=1}^{g} d(n_i)}{g} = \frac{2L}{g}$ where L denotes the number of ties in the network. If directed ties are investigated, a difference can be made between the indegree (amount of ties n_i is receiving) and the outdegree (amount of ties leaving n_i).

If analysing RIS from a social network perspective, it seems plausible to view RIS as network which is subdivided into several interconnected sub-networks. Within our model, those sub-networks are expressed by the different layers of RIS. Applying the methods of the SNA to the analysis of the RIS-layers then provides useful insights to the internal components of the networks and the respective resulting output of the RIS. How many of the agents are connected in and between the layers and how does this share impacts the outcome of the RIS (e.g. in terms of completed innovations)? To what extend does the structure of degrees at the core influences the dynamics of the network? Are there observable negative effects of network size?

Applying SNA to the analysis of RIS however implies necessarily to take into account the inherent economic logic of innovation networks. There has to be given *first* a formal description of the relevant contents and strength of ties between agents in a RIS. *Second*, the dynamics of the networks within the RIS have to be considered: at least within the core of RIS and the movement from and to the core, the dynamics are supposedly much stronger than in the networks usually investigated with SNA tools (as, for example, friendship networks). This dynamic aspect is a challenge for the application of the SNA. Furthermore, if one aims to explain and analyse the movement between the layers of RIS one has to take into account the reasons of why the agents are moving into the core (instead of conducting their innovation alone).

II.2.2.2 Network behavior of innovative agents

If a combination of behavioral traits (risk attitude, curiosity) and a critical relationship between aspiration level and actual performance is given activating the agent's willingness to innovate, the question arises if such an agent is oriented toward doing the innovation alone or by cooperating with other agents in a network.

Filling the gap in terms of micro-foundation for networking in general (cf. section I) necessitates to distinguish between

- the triggering condition for building a network (in what situation does a firm look out for network partners?)
- the matching condition for the networking agents (what is expected from the partners in a network?)

- the exchange condition (which resources are transferred between network agents under what conditions?) and finally
- the replication condition (is there a positive or negative feedback of the network results on the continuation of the network).

The ability of a network to overcome the 'distance' inherent in any market operation (cf. section I) is the common denominator of all these conditions. In economic terms this means to relate the cost for reducing the distance inherent in market relations to the yields which can be expected from this networking. The important costs in this context are the transportation cost (if distance is related to space)[19] and transaction costs (in all other dimensions of distance). The yields of networks are due to specificity advantages, to economies of scale and scope, to socializing risk (or uncertainty) and to solving a critical mass problem.

Cooperative innovations represent a specific type of network: (i)there are no structural asymmetries in terms of power and command between the networking agents; (ii)there is a formalized agreement about the goals of the network and the tasks of the network participants and finally (iii)generating and exchanging knowledge is an important part of the network activities (cf. Fritsch/Franke 2003; Antonelli 2000; Sternberg 2000).

An economic analysis of this type of network necessitates to relate the prospects for distance-reducing costs and yields to the nature of knowledge transformed and transferred in the network as well as to the nature of the relationships between the network partners. As regards to the nature of knowledge from an economic perspective the most important distinction is between 'public/explicit' on one side and 'private/implicit' on the other side. Between these two extreme cases there are many possible degrees of these attributes possible. It seems reasonable to assume that the cost to acquire a given set of knowledge (a subspecies of transaction costs) is the higher the more specific the knowledge is i.e. the more it tends to the 'private/implicit' extreme. Correspondingly the more this is the case the higher is the specificity advantage the knowledge acquiring agent can expect. Contrary to this economic *specificity effect* of knowledge transfer the *scale effect* is related simply to the number of knowledge components which are transferred between network partners. Here it seems appropriate to assume that the cost of transferring knowledge linearly depends on the number of knowledge components whereas the yields are increasing with the number of knowledge components due to economies of scale and scope.[20] Hence, as regards to the knowledge transfer the degree of knowledge specificity and the number of knowledge components are both influencing the microeconomic efficiency prospects of a network.

Concerning the nature of the relationships between the network partners trust is the most important factor in economic terms. Corresponding to the literature about trust and dynamic transaction costs (cf. Nooteboom 2002; Lorenz 1999) it can be expected, that trust operates on the side of cost and yields at the same time: On the one hand the more often a cooperation between two agents has been successfully accomplished the lower are the transaction costs in terms of finding an appropriate partner and coordinating the activities. On the other hand a well functioning partnership makes it easier to find new knowledge components and to increase the economic yield (e.g. by improving the product quality).

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[19] To analyse these costs is the basic tenet of economic geography.
[20] Cf. the formal analysis of transaction cost and asset specificity in Williamson 1985.

In formal terms this means that the transaction cost (TC) of an innovation network are a function of the knowledge specificity (s), the number of knowledge components (q) and trust (tr) in terms of the frequency of past successful knowledge transfers:

$$TC = f(s, q, tr)\,. \qquad [1]$$

The yield which can be expected from that innovation network (Y_{cop}) is influenced by the same arguments[21]:

$$Y_{cop} = g(s, q)\,. \qquad [2]$$

The countervailing effects of these factors are depicted in fig. 3.

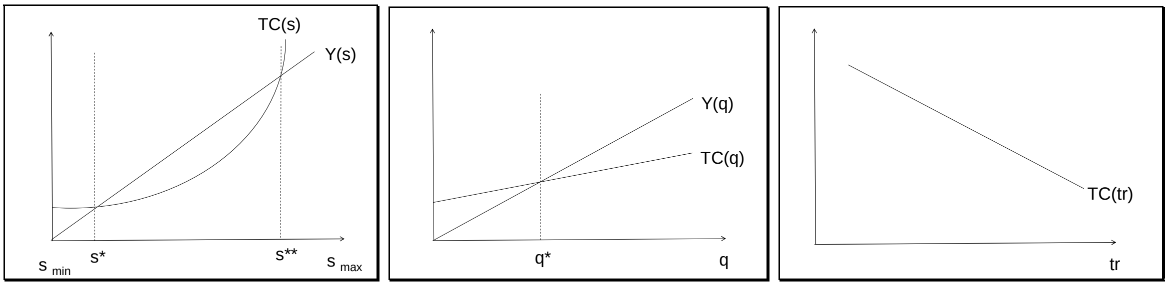

Fig. 3: Formal representation of factors influencing the microeconomic network efficiency

These factors for the microeconomic efficiency of networks are not transparent for the agents: they are realized in a time-dependent manner due to constraints and path-dependencies of the agents.

Taking into account these peculiarities of innovation networks the above mentioned general microeconomic conditions for networking can be specified:

- the triggering condition comprises not only a willingness to innovate but more specifically a combination of individual traits and competitive environment leading to a preference for cooperative innovation;
- the matching condition implies a correspondence between the dominant innovation drive of the agent looking for network partners on one side and knowledge endowments of these partners (including that the expected yields of a network fulfilling this matching condition exceed the transaction costs) on the other side;
- the exchange condition is related to a transfer of different types of knowledge and finally
- the replication condition is constituted by memorizing and communicating the experience of the network activity leading either to reinforcing or exiting the network.[22]

[21] Due to strong irregularity we skip the influence of trust here.

[22] In terms of the graphs depicted in fig. 3 this means that the frequency of successful network relation with a given partner is stagnating and the trust-dependent component of the transaction cost is no more diminishing.

III. Simulation model

III.1 Agents and their state variables

Agents are characterized by state variables and parameters in all the branches of the behavioral concept:

(i)They are endowed with financial and cognitive resources giving them more or less control over the environment they operate in. The cognitive resources comprise especially procedural and declarative knowledge. The procedural knowledge is tantamount to the ability of the agent to pursue different modes of action. These modes of action each comprise a specific way to perceive a situation and the possibilities to act, to evaluate these possibilities and to select one way to act. The declarative knowledge is related to the domain of activity the agent is engaged in. It is composed of common and specific elements.

(ii)They are determined by attitudes i.e. mental commitments giving them a basic orientation and mood in their way to act especially as regards to selecting the different modes of action. Hence, it is not only an external situation which influences the selection of a mode of action; additionally these attitudes play an essential role. Apart from risk acceptance and curiosity as basic personal traits the goals of the agents are considered as an important element of attitude. Agents have two (monetary) goals, namely to gain profit and to achieve a high market share.

(iii)As proposed by SNA agents are considered as socially embedded entities being influenced by proximate reference groups or past interaction experience. According to the Carnegie-approach this is reflected in the notion of the aspiration level, the plimsoll line for goal-achievement. This aspiration level is dynamically adjusted according to the actually reached current profit resp. market share (moving target). Furthermore, especially for the cooperative innovation, trust is an important result of interaction, being an agent-specific norm for selecting partners to cooperate with and for the decision about the continuation of a cooperation.

III.2 Modes of action and their selection

In the given context the modes of action are routine (as the default mode), imitation and innovation (the latter either as individual or as cooperative activity). Both novelty creating modes (innovation and imitation) require not only cognitive effort, but also temporal and financial resources.[23] The temporal and financial cost of an imitation project is smaller than the one of an innovation project. However, as regards to the possible returns, there is a disadvantage for an imitator compared to an innovator. The reason for this is that an imitator can only participate in the fraction of the total demand potential of the imitated innovative product which is not yet exhausted (in the course of diffusion of the product) at the time of accomplishment of the imitation. Generally, the expectation value for the demand potential assigned to a novel product just created is set proportionally to a certain power of the amount

[23] The time to develop an innovation (resp. imitation) is set probabilistically (drawn from a uniform random distribution) for each innovation (resp. imitation) project; the minimal and maximal value of the corresponding distributions are model parameters.

of declarative knowledge of the firm(s) that has/have created it, more precisely: to the number of knowledge domains where the firm(s) has/have got knowledge.[24]

Picking up the conceptual reflections in section II.2.1, the *innovation force* (F_2) itself consists of different components such as curiosity, the degree of satisfaction as regards to profits and the degree of satisfaction as regards to market shares. These degrees of satisfaction are indicated by the relationship of the aspiration level for profits (asp) and for market shares (asm) respectively to the corresponding actual performance level (p and m): $\frac{asp}{p}, \frac{asm}{m}$. The activation level of these different components is influenced by personal attitudes such as the exploration drive (w_0) as well as the weight and elasticity of the profit resp. market share aspiration (w_1 and ε_1 resp. w_2 and ε_2). Finally the innovation force is modulated by the expected cost for the innovation endeavour (*cin*) and the risk acceptance (α) which maps the willingness to accept the higher risk of innovation compared to imitation. The aspiration levels are updated at the end of each time step according to the difference equation

$$asp(t+1) = (1-\phi)\, asp(t) + \phi\, p(t) \qquad [3]$$

(and analogously for asm) where ϕ is the flexibility of adaptation, which is another personal trait ($0 \le \phi \le 1$).

According to the discussion in section II.2.1, curiosity is strongly related to the phenomenon of ‘slack’, i.e. the reserve capacities in terms of knowledge and finance. In any given time step this slack is tantamount to balancing the given state of knowledge and finance on one side and the amount needed of these resources for a given mode of action on the other side. Again, the intensity of curiosity triggered by this slack is depending on a personal trait, the exploration drive (w_0).

These considerations can be formalized as follows: We define three component forces f_i for curiosity (i=0), profit aspiration (i=1) and market share aspiration (i=2) by

$$f_0 = w_0\,(kr + fr) \qquad [4]$$

$$f_1 = w_1 \left(\frac{asp}{p}\right)^{\varepsilon_1} \qquad [5]$$

$$f_2 = w_2 \left(\frac{asm}{m}\right)^{\varepsilon_2}. \qquad [6]$$

Here kr and fr denote the knowledge resp. financial reserves of an agent in a given time step. The knowledge reserves are operationalized as the relation of the number of specific sharable knowledge domains (see below) where the agent possesses knowledge to the total number of sharable knowledge domains; the financial resources are operationalized as the share of the

[24] The background for this assumption is the positive relation between the broadness of knowledge and the firm's ability to meet the needs of (potential) customers.

current profit with respect to the current turnover. Finally, the innovation force F_2 is defined by

$$F_2 = \alpha \frac{f_0 + f_1 + f_2}{cin} \ . \qquad [7]$$

The *imitation force* (F_1) is different from the innovation force in three respects: *Firstly*, curiosity (or the personal exploration drive) plays no role in it (f_0 is omitted here). *Secondly*, there is a comparative difference in expected cost: *cim* < *cin*. *Thirdly*, the risk acceptance α, which was introduced to map the willingness to accept the higher risk of innovation compared to imitation (see above), is omitted here. Hence, the imitation force can be formalized as:

$$F_1 = \frac{f_1 + f_2}{cim} \ . \qquad [8]$$

Finally, we set the *preservation* (or routine) *force*

$$F_0 = 1 \qquad [9]$$

as a reference value.[25] Fig. 4 depicts the triggering conditions for the different modes of action and the feedback from the economic performance on these conditions as it is implemented in the simulation model.

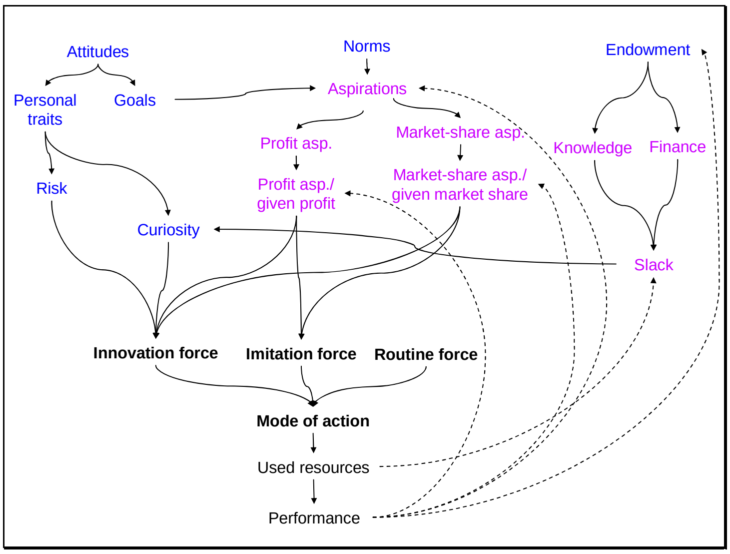

Fig. 4: Causal chain diagram for selecting mode of action in the simulation model

[25] Setting the preservation force to a constant is no restriction of generality since the absolute values of the forces F_i don't matter; it is only the ratio between them which determines the action mode. - There are three special or exceptional cases in which the selection mechanism mentioned above is not applied (or even not applicable):
(a) A new firm (start-up), which at the moment of its entry has zero turnover and zero profit, is assigned the action mode of innovation and in the case of cooperation the reason is assumed to be curiosity.
(b) When a new firm just has finished the development of its first innovation, it is assigned the routine action mode for a short period (which is determined by the mean development duration of an innovation).
(c) A firm with negative or zero profit which doesn't belong to case (b) is assigned the action mode of innovation and – if it is willing to cooperate – the cooperation reason (see the next subsection for a formal definition of this notion) is assumed to be profit dissatisfaction.

A firm agent which has selected the action mode of innovation still has two options (see above): He can try to develop an innovation on his own (individual innovation) or he can seek for cooperation in order to enable or facilitate the development of an innovation.

III.3 Cooperative innovations and their network implications

Two types of cooperations and, correspondingly, network relations are distinguished in the model; actually they are two subsequent phases of a cooperation's lifespan:

- An *innovation development cooperation* which aims at the development of a marketable innovative product. This process involves an exchange of (sharable) specific knowledge (see below) between the member firms of the cooperation. If the development of such an innovation is successfully finished, the innovation development cooperation is transformed into
- a *sales cooperation* for the innovative product or service. This means that the cooperation partners put the product on the market together and share the production cost and the returns of the sale of this product. The production of the innovative product is stopped and the sales cooperation is dissolved when the production cost is not covered by the sales returns.[26]

Given the importance of innovative cooperation for RIS it is necessary to specify the microeconomic conditions for this type of network activity (cf. section II.2.2.2) in the given modelling context. The *triggering conditions* for the innovation development cooperation are derived from the behavioral synthesis (cf. section II.2.1) and from empirical observations (cf. section III.4). According to this behavioral framework it is a combination of personal attitudes, subjective norms and endowment conditions which influences the orientation of an agent's willingness to innovate towards a cooperative mode for this innovation. *Firstly*, the three forces shaping the innovation drive (cf. above formula [4]-[6]) are basic for the agent's willingness to cooperate in terms of innovation.[27] These forces are related to the actual market performance of the agent. *Secondly*, different behavioral types of agents have a different propensity to cooperate. This takes into consideration that not only the actual market position is an important component for explaining cooperative innovations but also some 'deeper' attitudes stemming from different communication styles in different innovation milieus. *Thirdly*, at least in a regional context, the frequency of cooperative innovations can be observed. Hence, they can help to reduce the uncertainty associated with this type of innovative activity in that they facilitate the search for partners and demonstrate the possibilities to overcome opportunism. *Fourthly*, subsidies coming from political institutions

[26] Generally it holds: If for a firm agent – be it an innovator or an imitator – the production cost is not covered by the sales returns for two subsequent time steps and this deficit is increasing from the first of these time steps to the second, the firm agent stops the production of this product. The corresponding demand for the product is then transferred to other firm agents which produce the same product; if there are no such agents, the product disappears from the market and the corresponding demand is substituted by conventional products of the same branch.

[27] Contrary to the innovation force, this innovation drive is not discounted by any kind of aversion against risk or uncertainty; furthermore the calculation of expected costs does not play an essential role here.

and attributed to cooperating firms act as an exogenous incentive to form a cooperation. Fig. 5 shows how this triggering of cooperative innovation is embedded in the behavioral framework (solid lines) and how the outcome of cooperative innovation in turn influences these triggering conditions (dotted lines).

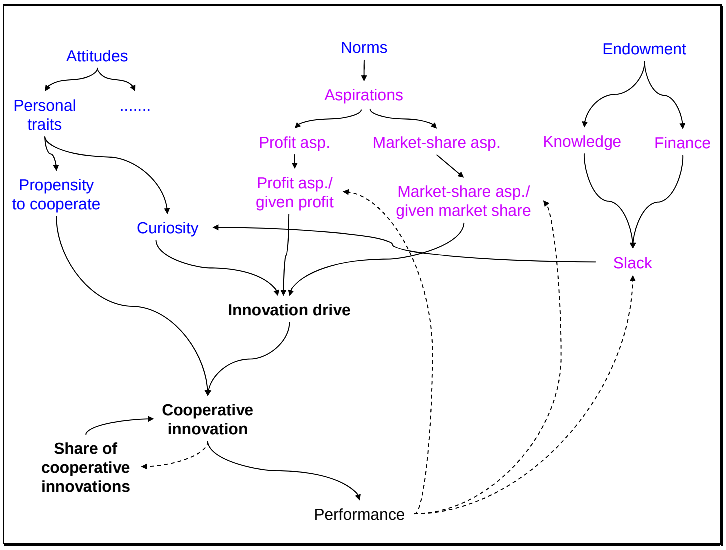

Fig. 5: Triggering conditions for cooperative innovation (without subsidies)

Denoting the propensity to cooperate by χ, the share of cooperative innovations N_c (related to the total number of innovations N) by $\frac{N_c}{N}$ and the amount of subsidies for cooperation by sc, the cooperation force of an agent is given by:

$$\mathrm{cp}(t) = (1 - ifb - iff - ifs)\,\chi + ifb\,\frac{N_c(t)}{N(t)} + iff\sum_{i=0}^{2} f_i(t) + ifs\,\mathrm{sc}\,, \qquad [10]$$

ifb, *iff* and *ifs* being parameterized weights for the different triggering forces. Actually a cooperation is pursued by an agent if this cooperation force is larger than a threshold (*ct*):

$$ct < \mathrm{cp}(t)\,. \qquad [11]$$

Given the willingness of an agent to switch to the cooperative innovation mode the matching procedure (*matching conditions*) has to be specified. *Matching condition 1* requires that the partners for a cooperation should either belong to the same branch or that they are related to each other as suppliers or customers.[28] *Matching condition 2* picks up the distinction between different kinds of knowledge the agent is equipped with (cf. section II.2.2.2):

- The first kind of knowledge is general knowledge. This is meant to be the necessary requirement for doing a business in any branch of activity and is essential for the communication between cooperation partners. This kind of knowledge is composed of generally accessible ('public') explicit knowledge and basic parts of implicit knowledge.

[28] At the beginning, each firm is assigned randomly a set of supplier firms, being fixed for the whole simulation.

- The second kind of knowledge is 'specific' knowledge. This kind of knowledge consists of ('private') explicit knowledge which is not generally accessible and of those parts of implicit knowledge which are not basic.

It is assumed here for the sake of simplicity that only the explicit parts of the specific knowledge are sharable between the partners of a cooperation; implicit knowledge is considered as not transferable.[29] Hence, the whole (declarative) knowledge base[30] of a firm agent is composed of three elements: common knowledge which is eo ipso not subject to transfer, transferable specific (explicit) knowledge and non-transferable specific (implicit) knowledge. This knowledge base is mapped in the model as vector components corresponding to knowledge domains in each of which the agent may or may not have knowledge.[31] Given this specifications the *matching condition 2* requires a minimum amount of common general knowledge components.[32] *Matching condition 3* relates the cooperation reason, which is defined as the dominant component in the innovation force of the agent, with the availability of certain knowledge components on the part of the cooperation partner(s):

- The cooperation reason should be the same for all partners.
- If the profit aspiration drive is the dominant innovation force, a sufficient amount of common transferable specific knowledge is required.
- If market share aspiration drive or curiosity are dominating the innovation drive, it is necessary for a successful matching of partners that each of the two agents has a sufficient amount of transferable specific knowledge which is complementary for the other.

If these matching conditions are fulfilled and there is someone to cooperate with, this causes a transaction cost (cf. section II.2.2.2). In specifying equation [1] it is assumed here that the transaction cost of a cooperative innovation depends linearly on trust, i.e. it is composed of a fixed element (*tcc*) which is the same for every transaction and an element which varies according to the level of trust one agent has in the other agent to cooperate with.[33] The maximum amount for this component of the transaction cost (no trust at all) is generally given by the parameter *tct*. This maximum is the more reduced, the more trust (tr) has been built up.[34] Formally this is depicted as:

$$\mathrm{TC(t)} = tcc + tct\,(1 - \mathrm{tr(t)}) \qquad [12]$$

If there is more than one candidate for cooperation the one for whom the trust is highest and the corresponding transaction cost are lowest is selected (cf. section II.2.2.2). This selection is

[29] Contrary to that it is sometimes assumed that implicit knowledge can be transferred at a certain cost (cf. e.g. Nonaka 2000; Cowan 2004). This is only reasonable if there are different degrees for the specificity of knowledge (cf. section II.2.2.2).

[30] The procedural knowledge (e.g. to know what to do in a given mode of action) is assumed to be the same for all agents.

[31] This means that there is no cardinal measure for the knowledge in a certain domain; each component of the agent's knowledge vector can take only one of the two values "available" (1) and "not available" (0).

[32] The distinction between 'general' and 'specific' knowledge is related to the availability of knowledge; the distinction between 'common' and 'individual' refers to the distinction between knowledge actually shared with other agents and knowledge being unique for one agent.

[33] Hence this variable element is not necessarily symmetric.

[34] It holds: $0 \leq \mathrm{tr} \leq 1$.

repeated (and the number of partners augmented) until the given budget earmarked for this purpose is exhausted.

Once the initiator of a cooperation has selected his partner(s), a process of knowledge transfer is started (*exchange condition*). This process lasts as long as the development duration of the innovation project (cf. above). In each time step, knowledge in one domain is transferred from the agent initiating the cooperation to his partner(s) and vice versa with a certain probability[35]. This probability (kp) depends on one hand positively on the trust (tr) of the knowledge-giving agent in the knowledge-receiving agent and on the other hand positively on the absorptive capacity (*ac*) of the receiving agent[36]. Formally, the probability for knowledge transfer is given by[37]

$$\mathrm{kp(t)} = se\,(\mathrm{tr(t)} - 1) + ac \qquad [13]$$

where *se* denotes the sensitivity of the transferring probability with respect to trust, which is another model parameter.[38]

Generally the *replication* or *continuation condition* for the cooperation is the expectation of the agents that in the case of a successful knowledge transfer the quality of the product can be improved and the demand for it will increase. The state variable depicting this feature of the cooperative innovation is trust. Each time this knowledge transfer doesn’t happen, the trust of the 'receiving' agent in the 'giving' one is diminished by a certain decrement; on the contrary, trust is raised by a certain increment each time the transfer actually happens. If the trust of a member of the cooperation falls beyond a certain threshold, this agent is leaving the cooperation.[39] The decrement and increment of trust as well as the threshold are model parameters.[40]

Fig. 6 gives shows the different microeconomic conditions for the cooperative innovation and the selection of cooperation partners as a flow diagram; Fig. 7 depicts the dynamics of trust and knowledge transfer within the cooperation process as well as the breaking off condition for cooperation.

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[35] This stochastic modelling reflects the conjectural nature of this process due to the bounded rationality of the agents. The corresponding random number is drawn for each partner and for each transfer direction, rendering these knowledge transfers stochastically independent.

[36] The absorptive capacity is conceptualized here simply as a given probability weight for the happening of the knowledge transfer. Sometimes the influence of absorptive capacity is modelled the other way round as a constraint for a perfect adoption of knowledge (cf Cowan 2004).

[37] If the right hand side of the formula is negative, the probability is set to 0. We assume $0 \le tr \le 1$ and $0 \le ac \le 1$.

[38] These endeavours to exchange knowledge within the cooperation cause an additional cost in every time step the cooperative innovation is given (cf. equation [1]).

[39] This can have different consequences for the cooperation depending on the size of the cooperation and the role the leaving agent plays in it: If the leaving agent is *not* the initiator of the cooperation (i.e. he has been selected as a cooperation partner by the initiator) *and* the number of remaining members is greater than one, there is no further consequence, i.e. the remaining members continue the cooperation process. If, on the contrary, the leaving agent *is* the initiator of the cooperation *or* if there is only one member left, the cooperation is completely broken off and the joint innovation development project is cancelled.

[40] Analogously to this stochastic process for maintaining or leaving a cooperative innovation, there is a lottery in the course of the process of individual innovation: during the development of an individual innovation, in each time step, the innovation project is abandoned with a certain probability, which is a model parameter.

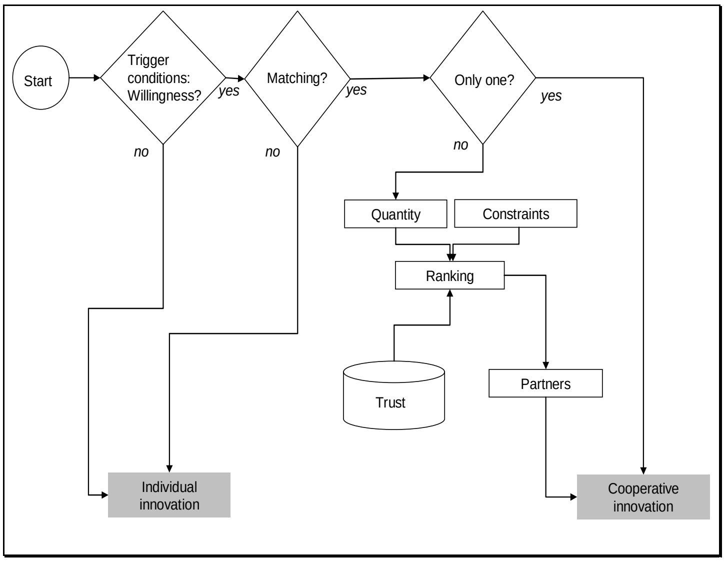

Fig. 6: Flow chart for selection of cooperation mode and partners for cooperative innovation

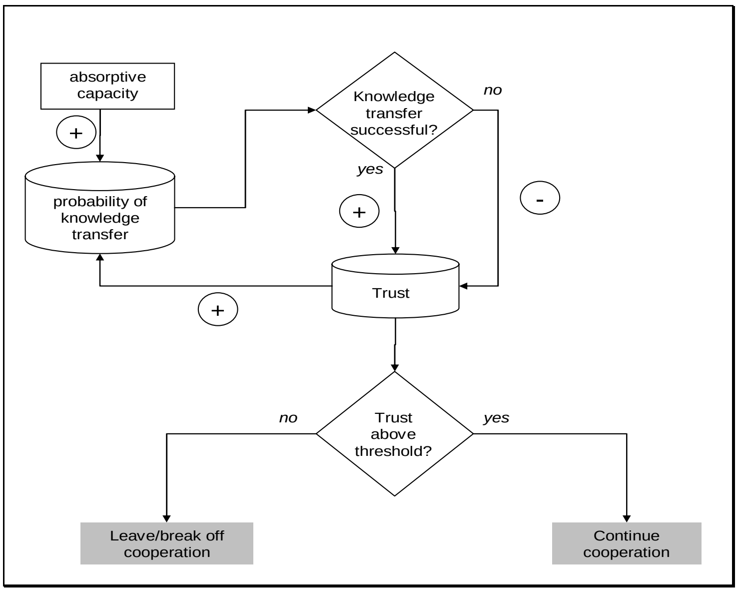

Fig. 7: Dynamics of trust during the innovation cooperation process

III.4 Empirical calibration of behavioral parameters

Calibrating MAS by using empirical data generally is a neglected topic. One reason for this might be the difficulty to gain agent-related data – especially in the economic realm where time is a scarce resource for both, the researcher and the researched. Another reason might be that there simply is no appropriate standard procedure for gathering these kinds of data. The data used for calibrating parts of the model sketched in the previous section were gained during the last year in Northern Hesse, Germany. The first dataset (D1) is based on a written questionnaire which was sent out by the authors of this article to 1783 firms. This sample consisted of the whole population of firms in Northern Hesse with more than three employees. These firms all belong to the manufacturing sector and related service sectors. Altogether, 527 firms responded to the survey (response rate of 29.6%). To gain the second dataset (D2), a random sample of 400 firms was drawn from the 527 firms which form the dataset D1. 207 firms responded to the second survey (51.6 %). Whereas the first questionnaire dealt with innovation, cooperation and networking more generally, the second one was especially designed to capture behavioral variables more thoroughly (cf. Daskalakis/Krömker 2007).

variable	para-meter	dataset	empirically derived means			Scale	transformed means		
			F_IR	F_IIM	F_ROUT		F_IR	F_IIM	F_ROUT
Risk acceptance	α	D1	2.3	2.0	-	1..5	3	2.5	3
		D2	4.1	4.2	3.5	1..6			
Exploration drive	w_0	D1[41]	3.3	2.6	-	1..5	0.25	0.2	0.15
		D2[42]	4.6	4.3	3.7	1..6			
Profit aspiration	w_1	D2	5.1	4.7	4.7	1..6	0.04	0.04	0.04
Market share aspiration	w_2	D2	4.9	3.9	4.3	1..6	0.06	0.04	0.05
Cooperation propensity	χ	D1	(70%)	(34.5%)	-	-	1.3	1	0.7
Regional trust	tr_0[43]	D1	4.0	3.9	-	1..5	0.75	0.75	0.75

Table 1: Statistical calibration of behavioral model parameters

variable	para-meter	data-set	Mann Whitney Test significances (2-tailed)			Kendall's Tau b correlation coefficient		
			F_IIM and F_IR	F_ROUT and F_IIM	F_ROUT and F_IR	F_IR	F_IIM	F_ROUT
Risk acceptance	α	D1	0.051	-	-	-0.54	-0.091	-
		D2	0.724	0.075	0.092	0.082	-0.057	-0.098
Exploration drive	w_0	D1[44]	0.000	-	-	0.236**	-0.205**	-
		D2[45]	0.231	0.143	0.001	0.199**	-0.089	-0.139*
Profit aspiration	w_1	D2	0.483	0.686	0.128	0.019	0.103	-0.125
Market share aspiration	w_2	D2	0.021	0.413	0.030	0.168*	-0.025	-0.067
Cooperation propensity	χ	D1	0.000	-	-	0.276**	- 0.120*	-
Regional trust	tr_0	D1	0.788	-	-	0.082	0.004	-

**indicates significance at 1% level (2-tailed); * indicates significance at 5% level (2-tailed)

Table 2: Statistical tests of behavioral model parameters

[41] This variable comprises the items „developing new markets“ and „creating new needs“.
[42] This variable comprises the items „experimental drive“ and “creativity”.
[43] This empirical value is only used to calibrate the initial value of the parameter.
[44] This variable comprises the items „developing new markets“„creating new need“.
[45] This variable comprises the items „experimental drive“ and “creativity”.

The design of the survey-questions is mostly based on five point (D1) and six point (D2) Likert scales. For calibrating the model, the means of the relevant parameters were firstly calculated and secondly linearly transformed in order to fit the model scales (cf. table 1). Correlation analyses (Kendall-Tau-b) as well as non-parametric tests (Mann-Whitney-U-Test) were applied in order to get statistical proves for the calibration (see table 2).
To derive the relevant means it necessary to distinguish different (behavioural) types of firms. With regard to the model, three types of firms are classified: radical innovators, imitators and routinizing firms (cf. table 3). The distribution of the type of firms (D1) is as follows: The share of Type F_IR in the product innovators was 30% and the share of the firms type F_IIM 15%. About 20% of the firms conducted no innovation at all (firm type F_Rout).[46] The share of the respective population of firms within the model simulation is set up accordingly.

Firm class	*Agent type*
Radical innovators (F_IR)[47]	Experimental
Imitators (F_IIM)[48]	Cautious
Routinizing firms (F_ROUT)	Conservative

Table 3: Mapping from empirical firm classes to agent types in the model.

Afterwards the relevant parameters have been identified. As regards to the model parameters presented in the previous sections two types have been distinguished:

- (i) Behavioral parameters which influence the choice of the modes of action. Here the designs of the questionnaires allow for investigating the following parameters: 'risk acceptance', 'exploration drive', 'market share aspiration' and 'profit aspiration'.
- (ii) Behavioral parameters which affect the choice between individual and cooperative innovation as well as the course of the cooperation. Those are 'propensity to cooperate' and 'trust toward the (regional) cooperation partner'.

These variables are evaluated according to the three different types of firm. Thus, we derive the parameter means for the respective firm types. The data being used are from both datasets. D2 has the advantage that the parameters matching (i) and (ii) are available for all three types of firms whereas in D1 those questions were only answered by the innovating firms. Hence, D2 provides a better foundation for the calibration. Unfortunately the absolute number of firms of type F_IIM in D2 is low. This might be the reason why differences between F_IR

[46] Altogether, about 80% of the 527 firms were innovating, most of them conducted product (and service) innovations (88%), the shares for process innovations and organisational innovations were 63% respectively 46%. – Product innovators who conducted incremental innovations and are not part of F_IR (55% of the product innovators) are excluded from our analysis. We thus analyze a very specific – yet quite relevant – section of possible innovation activities. This allows for implementing the empirical findings in the simulation model.
[46] Those firms might also have realized incremental innovation as well as imitation.
[47] Those firms might also have realized incremental innovation as well as imitation.
[48] Those firms solely accomplished imitation.

and F_IIM are quite clear cut when analysing the respective variables of D1 but not visible when using D2.[49]

Ad (i): The means of the behaviour parameters are illustrated in table 1. They rage from 2,3 to 4 within D1 and from 3,5 to 5,1 within D2.[50] Table 2 gives evidence that the correlations between the selected items and the types of firms are significant only in the case 'exploration drive' and 'market share aspiration'. The differences between the types of firms prove to be significant with regard to the following: in D1 imitators and radical innovators have different levels of 'risk acceptance' and 'exploration drive', the latter accepting more risk and having more 'exploration drive'. They do not differ with regard to 'profit aspiration'. Hence the transformed means for the latter are set equally for all three types of firms. In D2 there can be found significant differences again, concerning the 'exploration drive' (F_Rout vs. F_IR) as well as the 'market share aspiration' (F_IIM vs. F_IR; F_Rout vs. F_IR).

Ad (ii): To investigate the propensity to cooperate, we only refer to dataset D1. As shown above, the share of innovating firms was about 88%. Nearly 45% of these firms stated that they were involved in cooperative innovations, 37% of the cooperative innovations were conducted with regional partners. With a cooperation rate of about 70%, the firms of type F_IR were the most cooperative firm type (cooperation rate type F_IIM: 34,5%). In more detail: about 40% of the firms type F_IR had accomplished a cooperation during the investigated time span, about 47% still had been involved in innovation cooperation (type F_IIM: 9,1% and 29,1%).[51] Accordingly, the correlation between the items capturing the cooperation activities and both types of firm have a different level of significance and the statistics show a remarkable difference between both types of firms.

With regard to trust, our findings are ambivalent. Trust seems to be a relevant pre-condition for cooperative innovations as the means are relatively high. Yet, there are no significant correlations between the type of firms and the level of trust to be found. There are also no differences in the level of trust between the firm types. Therefore the corresponding transformed means are set equal for all three types of firms.[52] However, the statistics show that within cooperative innovations trust and knowledge exchange are interdependent. This is approved in the dataset D2 by a high correlation between the item „we have given our cooperation partners a lot of assistance" and the cooperative firms.[53]

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[49] The number of firm type F_IIM in D2 is 20. The respective answers of the firms concerning the behavioral foundation are thus only used to calibrate the model, if either the statistical evidences concerning those variables are sufficient and/or if statistical evidences from dataset D1 support the findings.

[50] Note the different Likert scales!

[51] Most of the cooperations (respective over 90%) were aligned to product innovations.

[52] There can be assed significant differences in the levels of trust towards regional and towards national partners: the regional cooperation partners were trusted more profoundly; level of significance (Mann-Whitney Test) for the two highest values: 0,001 (2-tailed).

[53] Kendall´s tau: 0,202; $p<0,01\%$. This is in accordance with the empirical findings in Daskalakis/Kauffeld (2006).

IV. Simulation results

IV.1 Change of RIS-layers over time

Analysing the dynamics of the RIS as a whole necessitates to look at the actions modes the agents pursue in the course of time and to decipher the network relations (according to the definition in section I) resulting therefrom. As regards to the frequency of the modes of action (cf. fig. 8 (above)) an inverse relationship between routine and imitation on one side and between imitation and innovation on the other side can be observed. This corresponds to the competition of behavioral forces expressed in equations [7]-[9]. Contrary to that the frequency of individual and cooperative innovation are moving in about the same direction. Because the individual innovation creates the knowledge resources being exchanged in the cooperative innovation, the latter follows the former with a time lag. The only mode of action increasing over the whole times span under investigation is the sales cooperation. This is due to the difference in the entry and exit dynamics for this special mode of cooperation: the entry is determined by successful former cooperative innovations whereas the exit depends on a loose cost condition (cf. section III.3). Generally it can be observed that there are two phases in the development of RIS: in the *first* phase up to about t=50 there is an increase in the modes of action related to creating novelties and a corresponding decrease of the frequency of agents being in a routine mode. In the *second* phase of RIS (for t>50) all modes of action (except the sales cooperation) fluctuate around a rather stable level.

In terms of the multi-layer concept ('onion-concept') of RIS this means that although the agents individually are continuously switching between the different layers there are patterns on the meso level in terms of the size of subpopulations on the different layers. In fig. 8 (middle) two snapshots for the RIS-onion composed of (numbered) agents on the different layers are depicted (t=60: RIS(60); t=120: RIS (120)). In such a graph the network relations either in an ongoing cooperative innovation or in a sales cooperation stemming from a former innovative collaboration are visible. What can be observed here is that agents with higher degrees (cf. section II.2.1) are more dissipated among all layers in RIS (120) compared to RIS (60) due to the persisting of sales cooperation. The possibility for an agent to earn profits or to maintain a market share by such sales cooperation might hinder the novelty creation. Fig. 8 (below) finally shows the network of trust ties for the corresponding time steps (RIS (60) and RIS (120)). These ties indicate all experience the agents made with each other in terms of knowledge exchange. Contrary to the relations in the actual innovation network and sales network the trust relations are not necessary symmetric between agents and they differ in value.[54]

Due to the difference in persistence three different network components can be associated with a RIS indicating the multiplexity property (cf. section II.2.1): a brittle and temporary innovation network, a more stable sales network on the medium range and a long term trust network. Whereas the sales network is a simple outcome of the innovation network, the trust network is an effect and cause for the innovation network at the same time because it is determining the replication of a given innovation network as well as the matching condition for a new innovation network.

[54] In terms of SNA: this network is represented by a directed asymmetric graph with ties of different values.

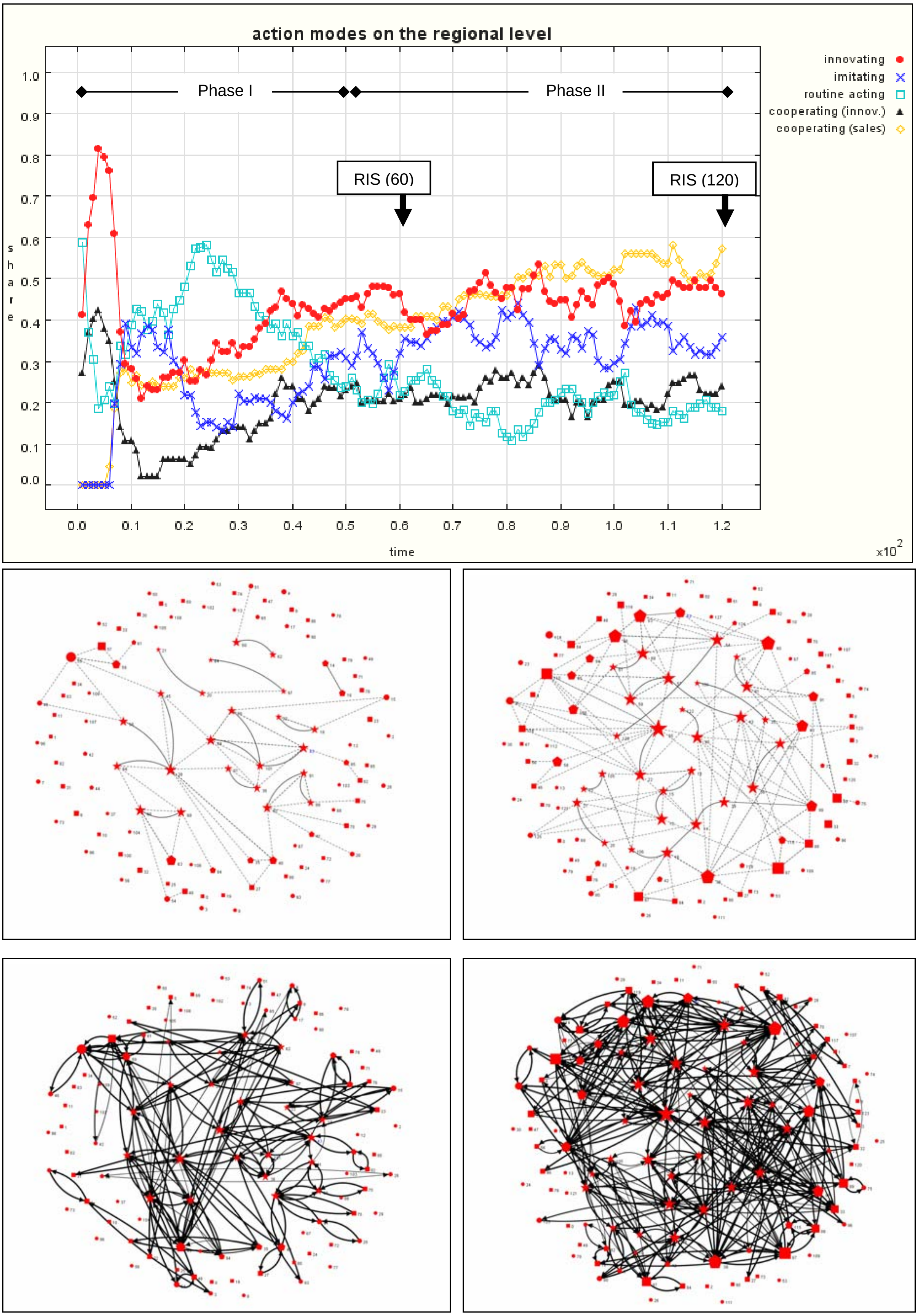

Fig. 8: (above) Modes of action over time; (middle) RIS(60) (stars, pentagons, squares and circles symbolizing agents in cooperative innovation, individual innovation, imitation and routine respectively; solid lines and dotted lines symbolizing network relation in cooperative innovation and sales cooperation respectively) and RIS (120); (below) Trust network in RIS (60) and RIS (120).

IV.2 Dynamic features of networks

According to the conceptualization of RIS given in section III.1 the cooperative innovations are the most important driving forces for the dynamics of RIS. In the context of the model framework proposed here they are the only source for the network relations between the agents belonging to RIS. These network relations are either related to knowledge and trust (innovation cooperation) or based on common market operations (sales cooperation).

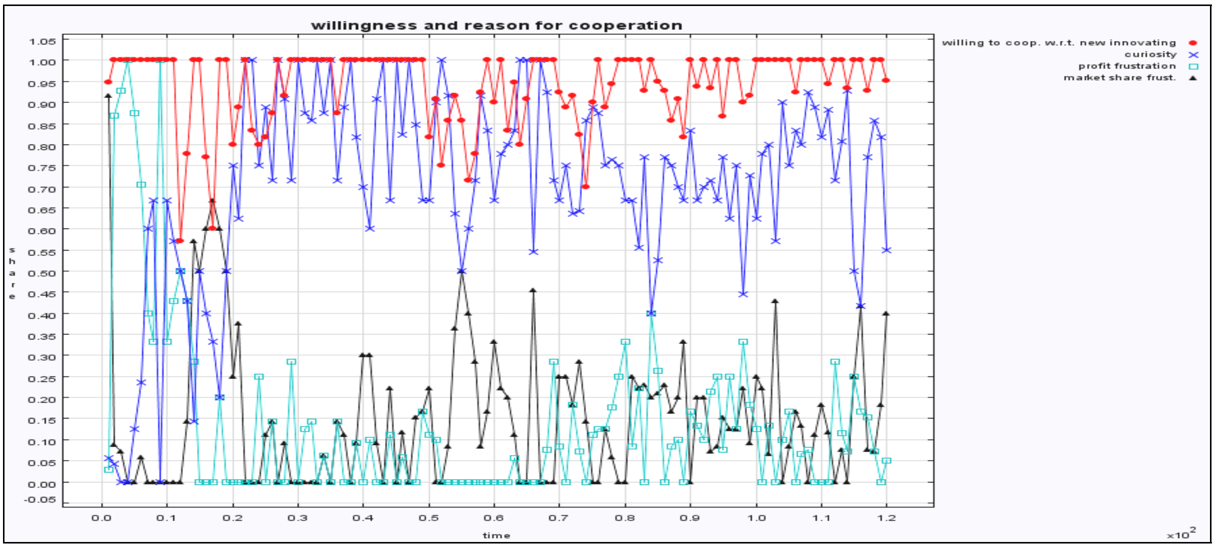

Fig. 9: Behavioral forces for cooperative innovation over time

The implementation of a cooperative innovation requires at least the fulfilling of the triggering as well as the matching conditions specified in section III.3. As a first step for analysing the background of the cooperative innovation activity in the RIS in fig. 9 the triggering conditions in terms of behavioral forces relevant for this type of activity are depicted over time. What is obvious here is that the willingness to cooperate is much more spread over the new innovative agents than the actual ability to implement such a cooperation (cf. fig. 8 (above)). This indicates that the knowledge related and financial requirements for these cooperations play an important role.[55] Furthermore fig. 9 reveals that the importance of curiosity for cooperative innovations is reduced in the second phase where the resources in terms of knowledge and finance are more efficiently used. Market share frustration and profit frustration (resulting from missing the corresponding aspiration levels) are getting more important in the second phase of RIS because competition is increasing. Nevertheless the peaks of the fluctuating frequency of realized cooperative innovations in the second phase of RIS (e.g. between t=75 and t=88 or between t=110 and t=115; cf. fig. 8(above)) seem to correlate with high levels of curiosity.

Focussing in a second step the realized cooperative innovations it can be observed that the constraints implied in the exchange as well as the replication conditions are preventing an uneven participation of agents in this type of activity. As regards to the frequency of being in

[55] Cf. the sensitivity analysis as regards to the role of transaction costs parameters (fig. 15) for a specification of this argument.

the core of RIS about 50% of the agents are there only up to three times; the other 50% are distributed in the range from being four times up to sixteen time in the core of RIS (cf. fig. 10). Hence, there seem to be some 'big players' in this RIS, but also a large number of agents with moderate or small engagement in innovation cooperations. Obviously there is no regular relationship between the number of agents and the frequency of finishing a cooperative innovation.

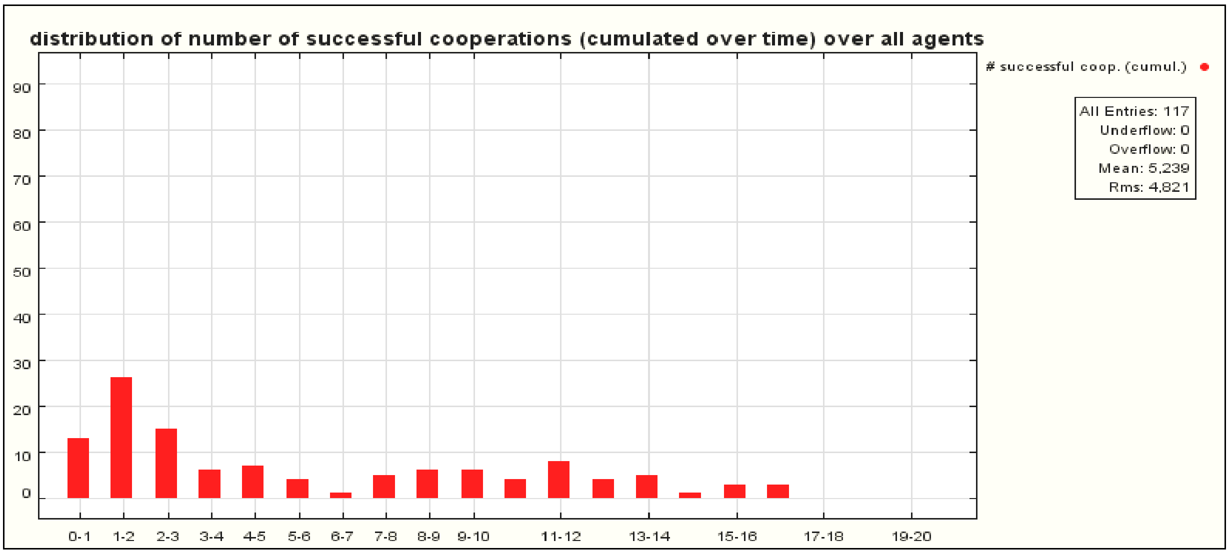

Fig. 10: Cumulated frequency of agents for being in the core of RIS

This assessment is confirmed if the mean degree (cf. the definition in section II.2.2.1) for the innovation network relations is plotted over time (cf. fig. 11). For the first phase of RIS this degree is slightly increasing. In the second phase of RIS it is almost stable with regards to the number of cooperative innovations (cf. fig. 8 (above)). A major cause for this result is certainly the limitation that a firm agent can only engage in one (cooperative or individual) innovation project at a time in our model. Hence, there is not much room for 'hubs' being established in such a network.

The picture changes if the sales cooperations (resulting from successful cooperative innovations) are included (cf. fig. 11). Due to the much softer constraint for this type of cooperation they can persist temporarily leading to an increasing number of network relations on the level of agents. This is indicated by the continuous increase in the mean degree for the network relations resulting from this cooperation in the second phase of RIS (after enough cooperative innovations have been finished). Against this backdrop temporary network-hubs are possible (mainly consisting of sales relations) as can be seen from fig. 8 (middle, left) e.g. for agents no. 55, 99 and in fig 8 (middle, right) e.g. for agents no. 38, 55 and 110. In fig. 12 the distribution of the degree for all network relations for all agents cumulated over the whole simulation span is shown. Obviously the corresponding frequency distribution is left skewed, i.e. the frequency decreases with the level of the degree. Hence, high level degrees do not occur very often or do not persist over a longer time period.

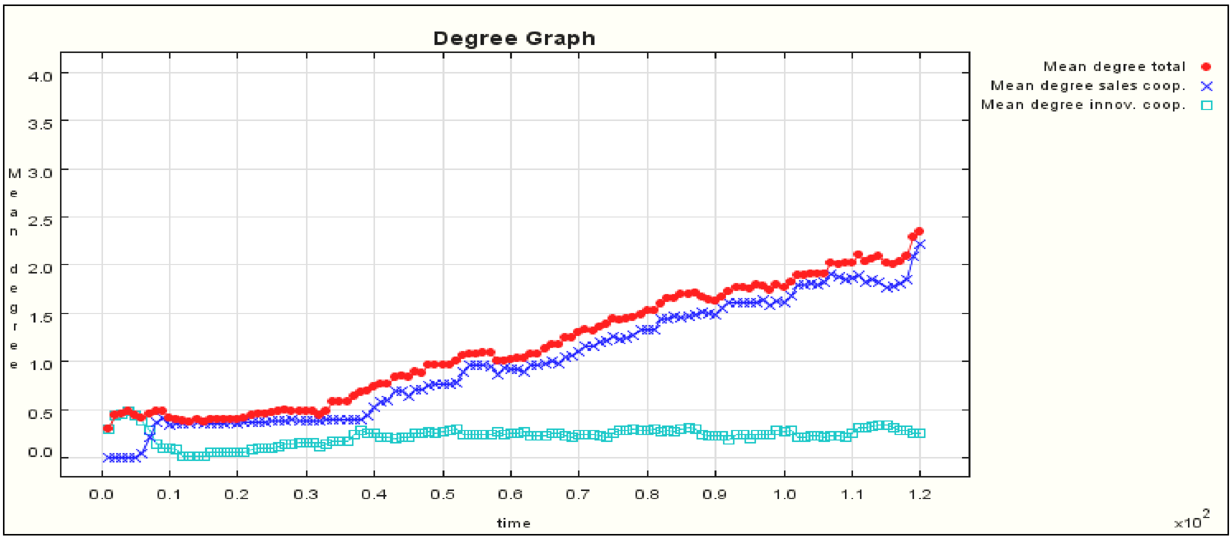

Fig. 11: Mean degrees for cooperation over time

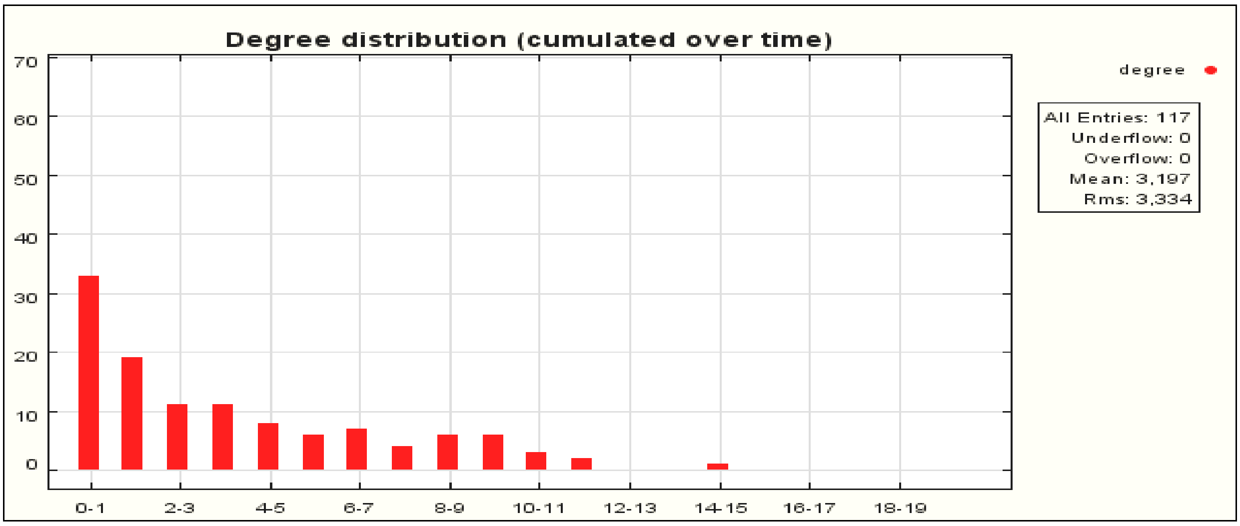

Fig. 12: Cumulated frequency distribution for cooperation degree

IV.3 Spread of knowledge

Individual and cooperative innovation are the two sources of new private (but sharable) knowledge in the given simulation model. For the sake of simplicity it is assumed here that in each time step for both types of innovation there is a chance to acquire only one additional element of sharable knowledge. This element of knowledge is related to a domain (e.g. knowledge about raw material of a certain type) and is coded in a binary manner ("1" means there is knowledge in a given domain; "0" means there is no knowledge in this domain). Hence, in every time step the number of agents getting new knowledge (switching from "0" to "1" in a given domain) can be counted for both types of innovation activities (fig. 13).

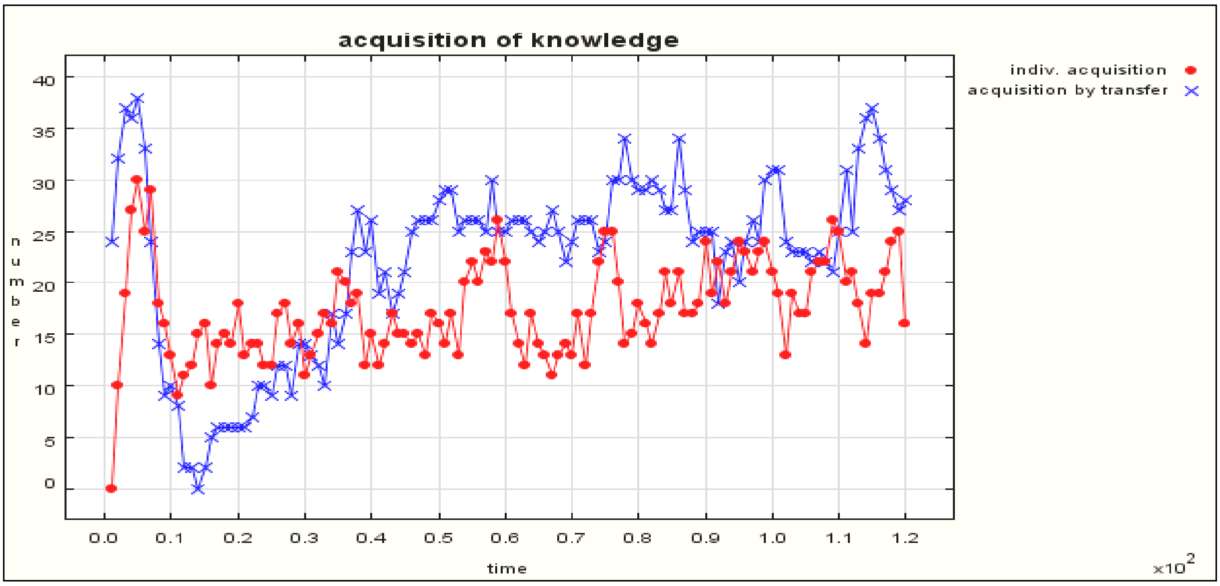

Fig. 13: Number of agents getting knew knowledge over time

For both types of innovation there is a tendency to deliver additional knowledge for an increased number of agents. In the first phase of RIS the number of agents involved in the spreading of knowledge in the case of cooperative innovation is growing faster than the corresponding number in the case of individual innovation: the former starts from a lower level and depends on the preceding of the individual innovation as a primary source. Apart from these tendencies the fluctuations of both sources for knowledge acquisition correspond to the time dependent frequency of the respective modes of action (cf. fig. 8 (above)).

It can be summarized that – except in the initial phase – the cooperative innovation plays an important role for the spreading of knowledge on the regional level. Due to the assumed possibility to transform this additional knowledge in quality improvements of commodities the number of agents being able to increase their market performance increases. This additional innovation potential triggers a growing value added and employment in the region as a whole.[56]

From the perspective of agents the acquisition of knowledge is only the first step of knowledge processing. The storage and the use of knowledge are other steps in this knowledge processing of agents which may imply that parts of the knowledge disappear due to memory constraints and to devaluation effects for unused or useless knowledge. Hence, the knowledge string of an agent varies in the course of time depending on the acquisition on one side and forgetting and devaluation of knowledge components on the other side. Therefore the behavioral differences of the agents do not only endow them with heterogeneous knowledge strings; furthermore the knowledge for the region a whole (measured by the frequency for the different knowledge domains of being a part of the agent's knowledge string) is different in every time step. Fig. 14 shows for selected knowledge domains how their distribution over the knowledge strings of agents evolve in the course of time. This indicates that different

[56] Cf. Beckenbach/Briegel/Daskalakis 2007 for a specification of these effects of cooperative innovation on the region as a whole.

knowledge domains are of different importance for the development of a region (as e.g. domain no. 32 compared with domain no. 0 in fig. 14).

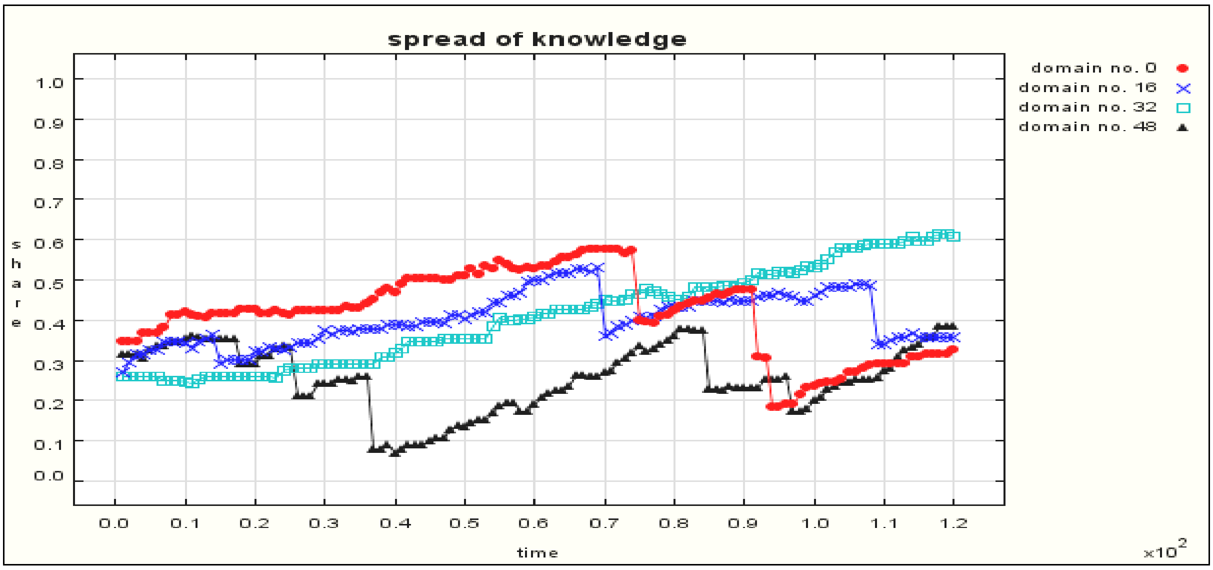

Fig. 14: Domain-specific spread of knowledge

IV.4 Sensitivity analysis

According to the conceptualization of RIS in section II.1 as well as according to the findings of the simulation model presented in section IV.3 the number of cooperative innovations and the related spread of knowledge between agents are the most important performance indicators of RIS. In the specification of the explanantia for this performance output (explanandum) of the simulation model (cf. especially section III.2 and III.3) cognitive as well as economic parameters have been used. Hence, it remains to be demonstrated how the above mentioned indicators for the core performance of RIS are influenced by these parameters.[57] In each of the following sensitivity tests the parameter space around the standard parameter configuration[58] used in section IV.1-IV.3 is investigated by means of Monte Carlo simulations.

In fig. 15 it is shown how the number of cooperative innovations and the average stock of sharable knowledge changes if the average aspiration flexibility (ϕ in equation [3]) and cooperation threshold (*ct* in inequation [11]) is varied. This reveals that an increase of the aspiration flexibility leads to an increase in finished cooperative innovations only if *ct* is not too high (fig. 15(a)). Due to the important role the cooperative innovation plays for the regional spread of knowledge basically the same critical relationship between the aspiration flexibility and the cooperation threshold holds for the average stock of sharable knowledge

[57] For getting a representation of the spread of knowledge by a real number the number of domains of sharable knowledge in the knowledge strings of the agents are simply summed up and divided by the number of agents (average stock of sharable knowledge).

[58] In fig.15 this configuration is marked by a black point.

(although this relationship is not as strong as in the former case because individual innovation is another source for the stock of knowledge) (fig. 15(b)).

In fig. 15(c)-(d) both outputs indicating the performance of the RIS-core are related to the parameter *ifb*, which determines the weight of the frequency component of the cooperation force (cf. equation [10]), and to the initial value for the trust level of the agents (tr(0)). The latter is important for the amount of transaction costs of a cooperative innovation (cf. equation [12]) and for the probability of knowledge transfer within such a cooperation (cf. equation [13]). Here it is obvious that for low and moderate values there is almost no influence of *ifb* on the frequency of successful cooperative innovations; for high values of this parameter there is even a negative influence on the former (cf. fig. 15(c)). This can be explained by the constraining effect an increase of *ifb* has on the propensity to cooperate (χ) according to equation [10]. Hence, only if low and medium range values for *ifb* are given an increase in the initial value for trust has a positive influence on the number of successful cooperative innovations (due to a reduction in transaction cost and an increase in the probability of knowledge transfer). Again the same delicate relationship between tr(0) and *ifb* is principally observable as regards to the average stock of sharable knowledge (cf. fig. 15(d)) (though not in the same drastic manner because private innovation is another source for knowledge generation).

Finally the dynamics of the RIS-core have been checked for varying the transaction cost parameter *tcc* (cf. equation [12]) on one side and the amount of subsidies (sc; cf. equation [10]) on the other side (cf. fig. 15(e)-(f)). In this constellation the increase of the transaction cost parameter has almost no influence on the frequency of cooperative innovations. Hence, to pursue a cooperative innovation seems not to be a purely financial problem. This constellation changes if – due to subsidies – the cooperation force (as expressed in equation [10]) increases and the financial constraint matters: now an increase in transaction costs reduces the number of cooperative innovations (cf. fig 15(e)). Contrary to that enhancing the amount of subsidies increases the number of cooperative innovations for any given level of transaction costs. Due to the partial role of cooperative innovations for knowledge generation these relationships do not hold in the same way for the average stock of sharable knowledge (cf. fig. 15(f)). In this case a low level of transaction costs and a moderately high level of subsidies give the best results.

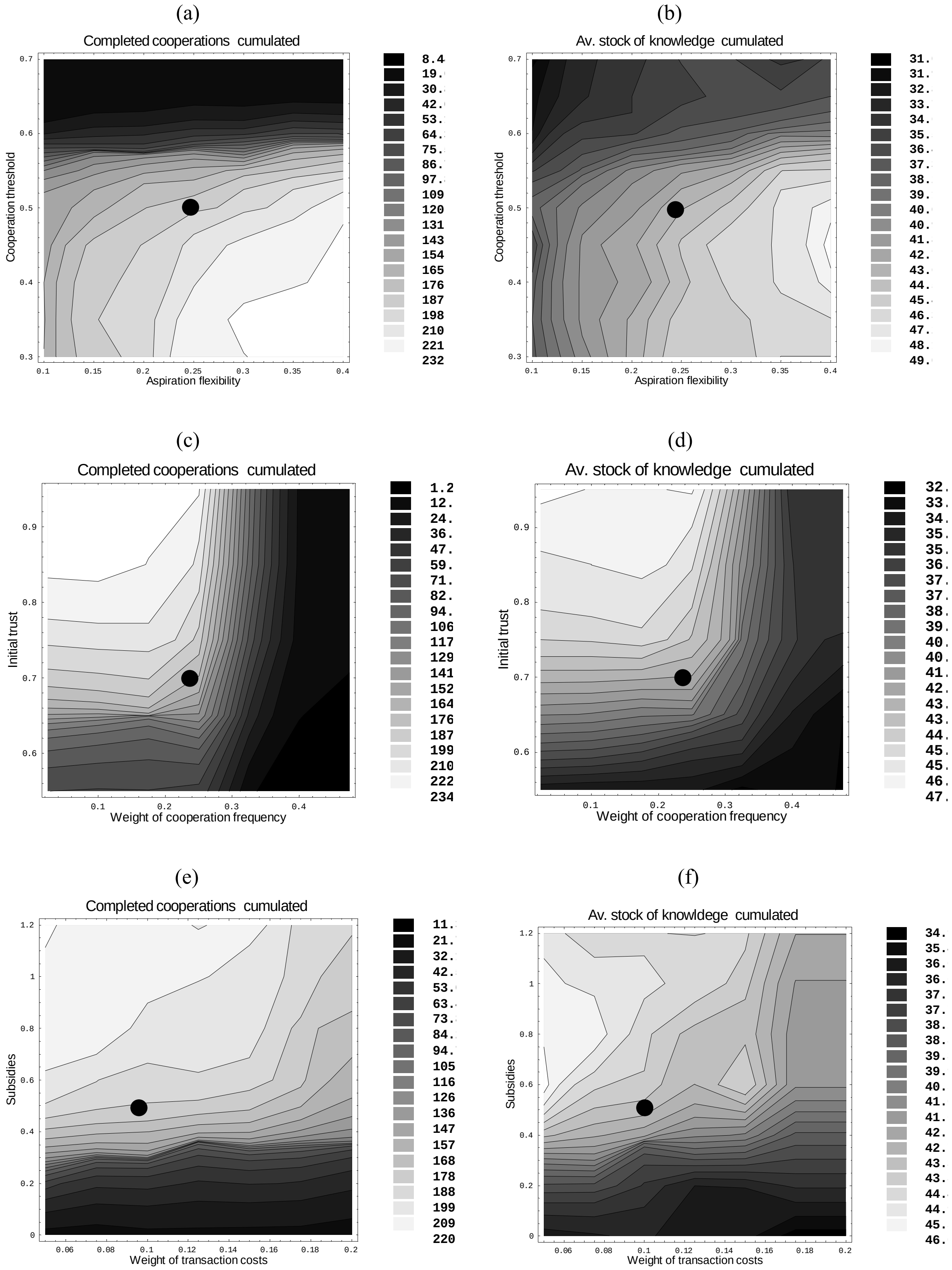

Fig. 15: Sensitivity analysis

V. Conclusions

In this contribution it is shown how one can proceed if the often neglected internal dynamics of RIS shall be explained. Then the agents, their different modes of action as well as the coordination of their activities by markets, networks and institutions have to be taken into account. It was proposed here to explain the internal dynamics of RIS by referring to different layers in terms of action modes the agents can pursue. This implies to explain the selection of these different modes of action by considering behavioral as well as situational components. In that context the core of RIS is the mode of cooperative innovation of several agents in a region. This mode of action was identified as a source for multiplex network relations lying between market relations on one side and hierarchy relations on the other side.

The simulations with the agent-based model of RIS show the emergence of patterns as regards to the frequency of the different modes of action and hence to the dynamics on the different layers of RIS. These patterns on the regional (meso) level 'grow' out of the ongoing behavioral dynamics of the individuals (micro-level) continuously switching between the different modes of action. These patterns on the meso-level comprise different evolution paths for the network components: a brittle development of cooperative innovations on a rather low level, a stable medium range growth of sales cooperation and a high level growth for trust relations.

Finally the sensitivity analyses as regards to the parameters for cooperative innovation reveal a 'network landscape' behind the observable dynamics of RIS. Broadening the perspective of a singular path to include such a network landscape sheds light on the conditions for good network performance in terms of parameter constellations. Hence, such simulations can be a starting point for a bottom up improvement of the performance of RIS and the networks included. This is in sharp contrast to the usual top down optimization perspective in network research and the corresponding perspective of a designer or even planner of a RIS.

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