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Organizational Learning and Knowledge Spillover in Innovation Networks: Agent-Based Approach (Extending SKIN Framework)

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ABSTRACT:
In knowledge-based economy, knowledge has a public good and non-rivalry nature. Firms build their own knowledge stock not only by means of internal R&D and collaboration with partners, but also by means of previously spilled over knowledge of other firms and public research laboratories (such as universities). Firms based on their absorptive capacity, and level of intra-industry and extra-industry knowledge spillover could learn to produce innovative products. SKIN (Simulating Knowledge Dynamics in Innovation Networks) is an agent-base framework to study knowledge dynamics between innovative firms. The basic SKIN framework does not support absorptive capacity and knowledge spillover concepts, so this paper extends basic SKIN framework and adds absorptive capacity and knowledge spillover to it, and experiments -by simulation- the effect of these concepts on organizational learning. The results show that absorptive capacity has a moderating effect on organizational learning. This effect has been measured by the firms' population, average innovation length, Herfindahl Index and network density.

Keywords: *Organizational learning, Absorptive capacity, Knowledge spillover, SKIN framework, Agent-based modeling*

INTRODUCTION

There are several ways to classify the innovation literature and choosing one will always lead to interferences. Alois Schumpeter was the first economists who intensively investigating the phenomenon of innovation in his works of the 1930s and 1940s through emphasizing the role of innovation in the economy. During the second half of the 20^{th} century several other schools of innovation theory emerged, tackling the phenomenon of innovation from different perspectives.

As Schumpeter's theories are almost impossible to be modeled mathematically the standard neoclassic theory tried to explain economic growth by innovation and turned out not to be capable of explaining economic growth, which is connected to disequilibrium dynamics. There have been attempts to bring growth induced by technological change and thus innovation, neoclassical models especially made by Romer (1990) with the "endogenous" growth theory. However, innovation itself - still associated with "falling like manna from heaven" - is seen as the "endogenous result of the system

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dynamics" (Antonelli and Ferraris, 2009).

Based on the work of Nelson and Winter (1982), Schumpeterian thoughts were enriched by focusing on economic evolution, innovations coming out of knowledge exchange between organizations and the importance of network structures. Stressing that the dynamic factor of innovation-happening incrementally or radically- is characterized by feedback effects which can be seen as the trigger for the evolutionary approach.

Neo-Schumpeterian and evolutionary approaches are acknowledging that innovation can be seen on the macro level but is generated and thus only to be understood on the micro level. The Systems of Innovation approach provides a framework to analyze and classify innovation systems in which actors like firms, governmental institutions and entrepreneurs are embedded. (Pyka, 1999)

Innovation Networks and Agent-Based Modeling

Gilbert et al. (2001), argue that innovation network approach can be a suitable approach for modeling the creation of knowledge and thus innovation. This approach is closely connected to evolutionary approach of innovation and complexity and adaptive systems school (Anderson, 1999). Mahmoudzadeh and Jassbi (2011) argue that agent-based modeling is the best way to model complex and adaptive systems. There is no general agreement on the definition of an agent. But the term is usually used to describe self-contained programs that can control their own actions based on their perceptions of their operating environments. Agent applications has been much influenced by work in artificial intelligence (AI), especially a subfield of AI called distributed artificial intelligence (DAI) which is concerned with the properties of and the design of networks of interacting agents (Gilbert, 2005).

In agent-based modeling (ABM), a system is modeled as a collection of autonomous decision making entities called agents. It enables one to build models where individual entities and their interactions are directly represented. In comparison with variable-based approaches using structural equations, or system based approaches using differential equations, agent based simulation offers the possibility of modeling individual heterogeneity. It allows modelers to represent in a natural way multiple scales of analysis, the emergence of structures at the macro level from individuals' action, and various kind of adaptation and learning, none of which is easy to do with other modeling approaches (Gilbert, 2008).

Bonabeau (2002), argues that the ABM has benefits over other modeling methods which could be captured in the following statements: (i) ABM captures emergent phenomena; (ii) ABM provides a natural description of a system; (iii) ABM is flexible. Grimm and Railsback (2005) argue that scientists who working in CS, attempt to understand the dynamics of systems of adaptive individuals, by using agent-based computer simulation.

SKIN (Simulating Knowledge Dynamics in Innovation Networks) Framework

Ahrweiler et al. (2004), have built a framework for modeling knowledge dynamics in innovation networks called SKIN (Simulating Knowledge dynamics in Innovation Networks) based on agent based modeling technique. SKIN is a multi-agent model containing heterogeneous agents which act in a complex and changing environment. Its agents are innovative firms which try to sell their innovations to other agents and end users who also have to buy raw materials or more sophisticated inputs from other agents (or material suppliers) in order to produce their outputs. Each firm tries to improve its innovation performance and its sales by improving its knowledge base through incremental or radical learning, and co-operation and networking with other agents. An agent is a firm with an individual knowledge base. This knowledge base is called its kene (Gilbert et al., 2010) and consists of a number of "units of knowledge". Each unit is represented as a triple consisting of a firm's capability C in a scientific, technological or business domain, its ability A to perform a certain application in this field and the expertise level E the firm has achieved with respect to this ability the firm's kene is its collection of C/A/E-triples (figure 1).

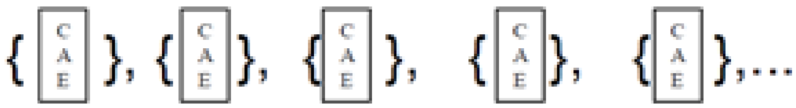

Figure 1: Firm's Kene

Firms apply their knowledge to create innovative products that have a chance to be successful in the market. The special focus of a firm, its potential innovation, is called an innovation hypothesis. In the model, the innovation hypothesis (IH) consists of a subset of the firm's kene triples. A firm's product, P, is generated from its innovation hypothesis as (Eq. 1):

$$P = (C1 * A1) + (C3 * A3) + (C4 * A4) + \cdots \text{modulus} N \quad (1)$$

where N is the total number of products ever possible within the model.

Research Strategy

Incremental research means that a firm tries to improve its product by altering one of its abilities chosen from the triples in its innovation hypothesis while generally sticking to its focal capabilities. Radical research a firm can choose to perform radical research to explore a completely different area of market opportunities. This is done by randomly changing one capability in the kene for a new one and then forming an innovation hypothesis from its kene set.

Partnership Strategy

Partnership in this model is done through comparing the firm's own capabilities in its innovation hypothesis and the possible partner's capabilities as seen in its advertisement. Possible partners are chosen by two different strategies: conservative and progressive.

Conservative Strategy

Applying the conservative strategy, a firm will be attracted by a possible partner that has similar capabilities.

Progressive Strategy

Using a progressive strategy the attraction is based on the difference between the capability sets.

Organizational Learning and Knowledge Spillover

Romer (1987) in definition of endogenous growth theory, extends the production function as below (Eq. 2):

$$Y = F(K, L, e)\Omega(E) \quad (2)$$

Which represents a firm's production possibilities with capital K, labor input L and a private stock of knowledge e when the aggregate stock of public knowledge (knowledge spillover) is E. Cohen and Levinthal (1990) emphasize these two types of knowledge in a firm's production function and define a dual role for a firm's R&D. They argue that while R&D generates innovations, it also develops the firm's ability to identify, assimilate and exploit knowledge from the environment, which they call that a firm's 'learning' or 'absorptive capacity'. So, absorptive capacity includes the firm's ability to exploit outside knowledge of a more intermediate sort, such as basic research findings and also applied researches. They argue that the former is a kind of learning-by-doing which refers to be more efficient at doing what it is already doing. In contrast, with absorptive capacity a firm may acquire outside knowledge that will permit to do something quite different. March (1991) defines these two types of organizational learning as, *exploration* which includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery, innovation and *exploitation* which includes such things as refinement, choice, production, efficiency, selection, implementation, execution. He argues that there is a trade-off between these two types of learning and managers should balance them. Cohen and Levinthal (1989) define a firm's knowledge stock as below (Eq. 3):

$$z_i = M_i + \gamma_i(\theta \sum_{j \neq i} M_j + T) \quad (3)$$

Where M_i is a firm's investment in R&D, $\gamma_i$is the fraction of knowledge in the public domain that the firm is able to assimilate and exploit, and represents the firm's absorptive capacity. $\theta$is the degree of intra-industry spillovers, and T is the level of extra-industry knowledge. Other firms' investment in research and development, represented by $M_j$for $\neq i$. They also define γ_i as a function of M_i and a parameter β (Eq. 4):

$$\gamma_i \equiv \gamma(M_i, \beta) \quad (4)$$

The variable β reflects the characteristics of outside knowledge that make R&D more or less critical to the maintenance and development of absorptive capacity. When outside knowledge is less targeted to the firm's particular needs and concerns (like as university laboratories involved in basic research), a firm's own R&D becomes more important to exploit public knowledge and vice versa (like as contract research laboratories and input suppliers).

Extending SKIN Framework

Adding New Features to SKIN Framework

In SKIN framework a firm's Kene plays the role of knowledge stock. So, based on Cohen and Leventhal's definition of a firm's knowledge stock (Eqs. 3,4) this paper extends SKIN framework by defining a new type of agent as research laboratories which produce basic knowledge (T in Eq.3). Since in different domains of study the rate of producing basic knowledge is varying, so this paper defines three levels of public knowledge production rate. (It is important in many studies researchers follow to study the relationship between the rate of producing basic knowledge and the rate of producing innovative products). Also for implementing degree of intra-industry spillover, a new variable has been defined which represents the status of knowledge spillover of business domain under study. (Knowledge in some business domains is very exclusive or secret while it is public in some others).

To make it possible to study the results of different scenarios in model, we have added a new partnership strategy named 'absorptive capacity' (figure 2). In this case, based on Eq. 4, firms have a progressive partnership strategy with their previous partners, suppliers and customers (more target firms). But they have a conservative partnership strategy with other firms and research laboratories (less targeted firms).

There are many measures, to evaluate different scenarios in SKIN framework. Gilbert et al. (2007) use firms' population as a major measure to evaluate different scenarios to study organizational learning. Blom and Hildrum (2012) use firms' population, Average Innovation Hypothesis (IH) length and Concentration Index to study knowledge dynamics in Nordic Internet Service Provider (ISP) industry. Ahrweiler et al. (2004), use Herfindahl Index as another measure to evaluate model results.

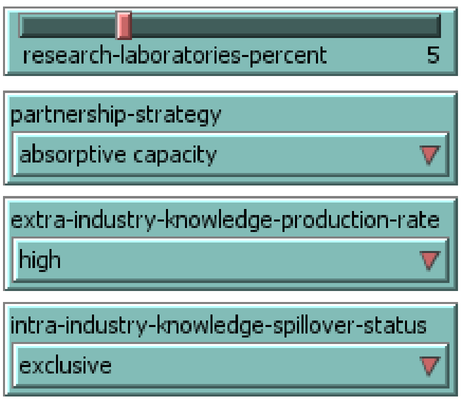

Figure 2: New features added to SKIN framework

Firms' Population

Variations in the population of firms show the attractiveness and successfulness of a business domain.

Average Innovation Hypothesis (IH) Length

A higher average IH length, means that there are so many capabilities available for firms in the form of public knowledge and firms could produce more different products.

Herfindahl Index

Herfindahl Index is a measure of the size of firms in relation to the industry and an indicator of the amount of competition among them. If an industry has n firms with outputs $q_1 > q_2 > q_3 > \ldots > q_n$, we have Eq. 5:

$$Q = \sum_{i=1}^{n} q_i \qquad (5)$$

So the market share of firm is as Eq. 6:

$$s_i = \frac{q_i}{Q} \qquad (6)$$

and finally Herfindahl Index is as Eq. 7:

$$H = \sum_{i=1}^{n} s_i^2 \qquad (7)$$

This index rests in the fact that the market shares are squared prior to being summed, giving additional weight to firms with larger size. Some countries compare H with a certain threshold, and some other prefer to study changes in its value.

Social Networks Analysis (Network Density)

As well as the above mentioned measures which already have been used in different studies we use network density measure to evaluate the degree of complexity in innovation networks. Network density is a network level statistics in social networks analysis and is ratio of number of links between nodes to total number of possible links.

Different Scenarios of Experimentation

By extending SKIN framework and adding absorptive capacity and knowledge spillover features to it, now, we could experiment different scenarios and compare their results.

Scenario 1: Incremental Research (The Baseline Model)

This is the baseline model in our experimentation, firms could do incremental research without establishing a partnership relation (figure 3).

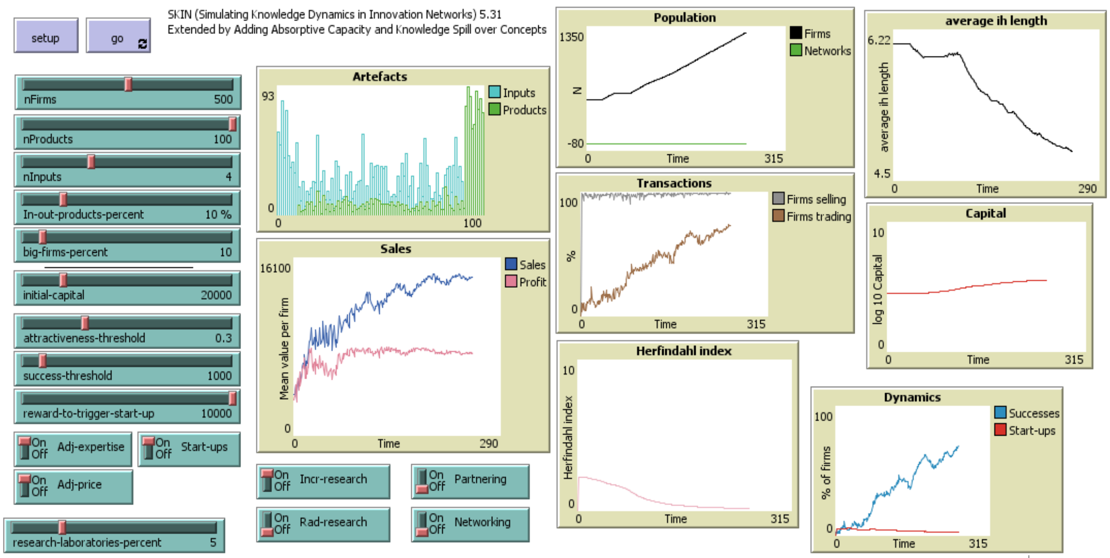

Figure 3: Output of scenari 1: Incremental research (The baseline model)

Scenario 2: Conservative Partnering and Incremental Research

In this scenario firms do incremental research and establish partnership relation with conservative strategy (figure 4).

Scenario 3: Progressive Partnering and Incremental Research

In this scenario firms do incremental research and establish partnership relation with progressive strategy (figure 5).

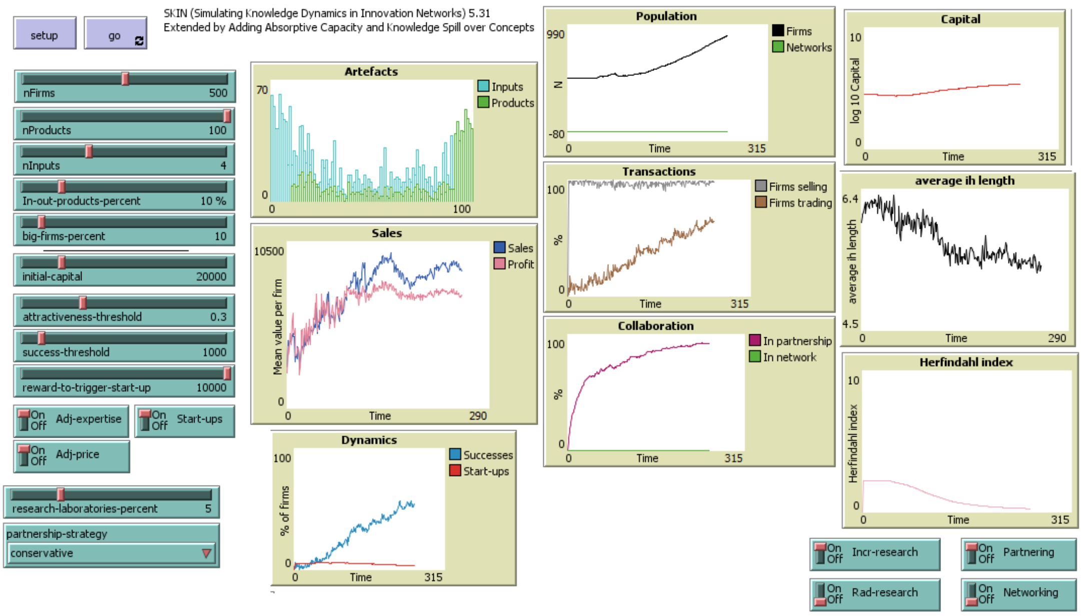

Figure 4: Output of scenario 2: Conservative partnering and incremental research

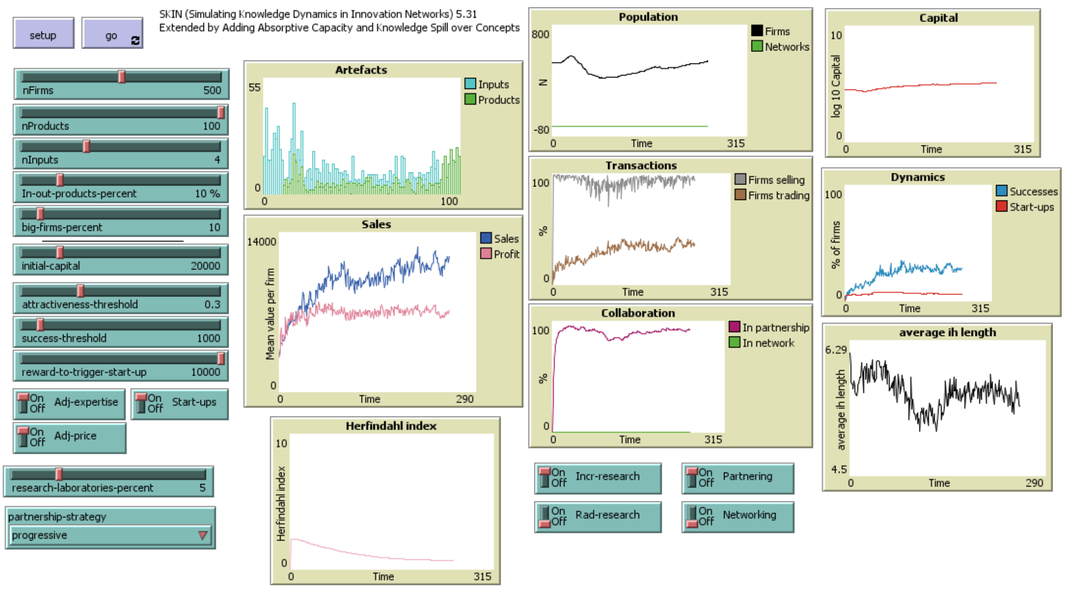

Figure 5: Output of scenario 3: Progressive partnering and incremental research

Scenario 4: Absorptive Capacity Partnering and Incremental Research

In this scenario firms do incremental research and establish partnership relation based on their absorptive capacity (figure 6).

RESULTS AND DISCUSSION

Population: Firms' population in scenario 4 is higher than scenarios 2 and 3 which shows that absorptive capacity strategy has better performance respect to conservative and progressive strategies (figure 7).

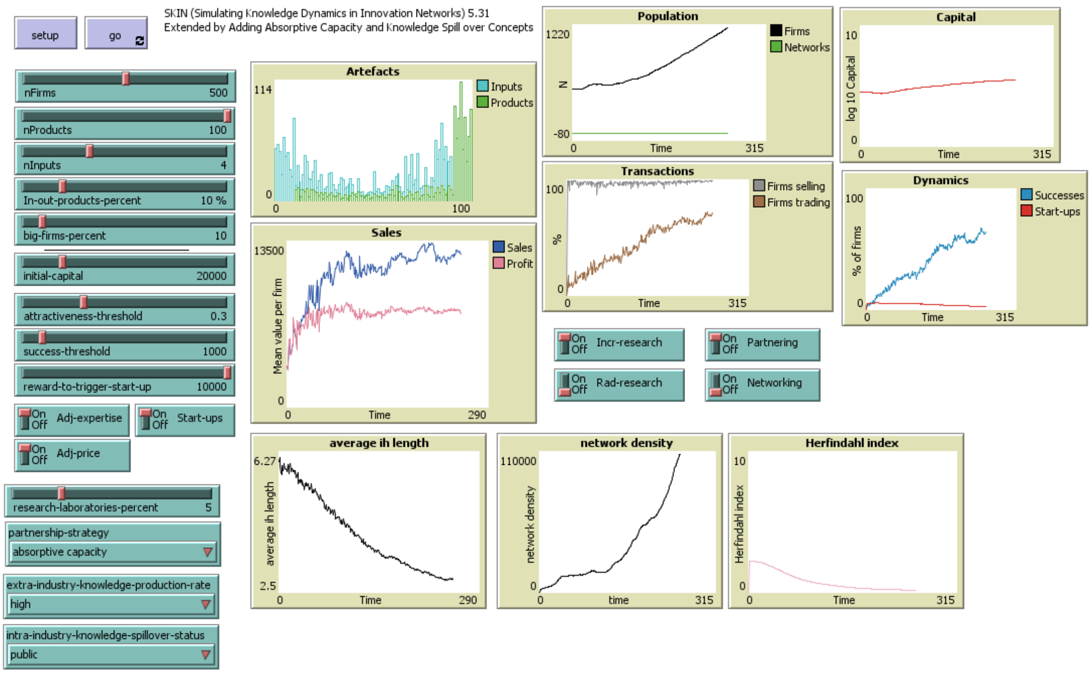

Figure 6: Output of scenario4: Absorptive capacity and incremental research

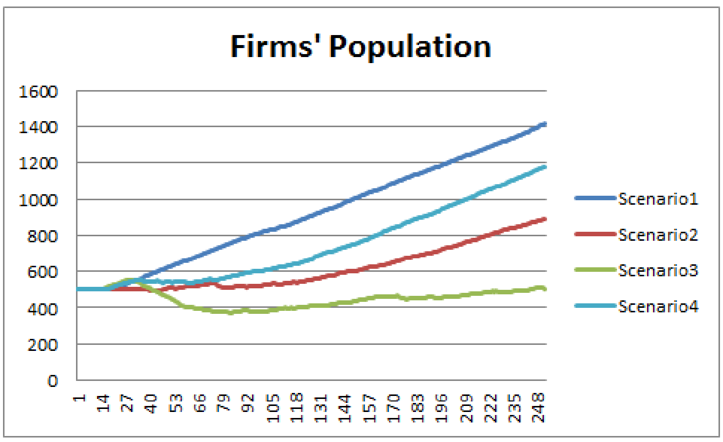

Figure 7: Comparison of firms' population in different scenarios

Average IH Length: Scenarios 2, 3 because of using other firms' capabilities has an average length higher than other scenarios. Scenario 4 because of using public knowledge, and knowledge which is available for all of firms has a lower average IH length (figure 8).

Herfindahl Index: H-index was calculated by each firm's capital instead of market share. So figure below shows a lower H-index for scenario 4 respect to scenarios 2 and 3 (figure 9).

Network Density: There is an increase in network density in scenario 4 because of using public knowledge by the firms (figure 10).

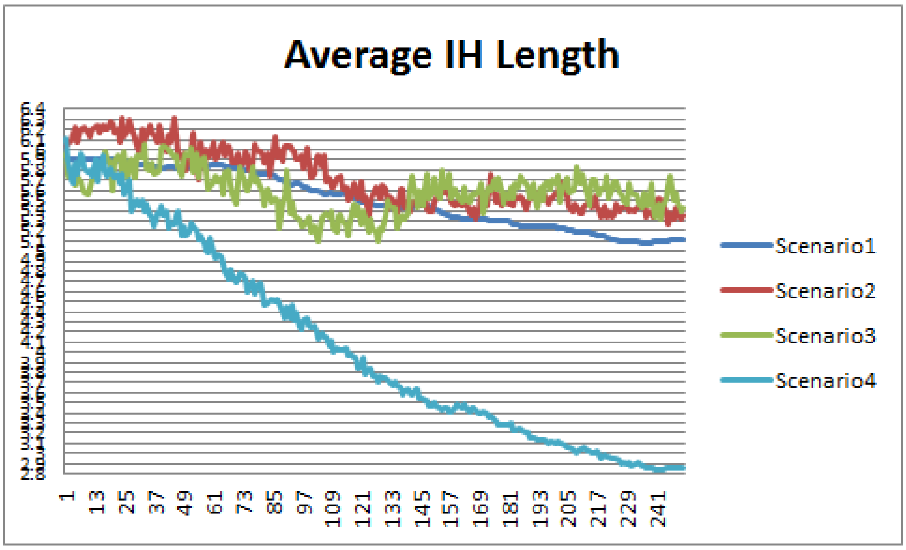

Figure 8: Comparison of firms' average IH length in different scenarios

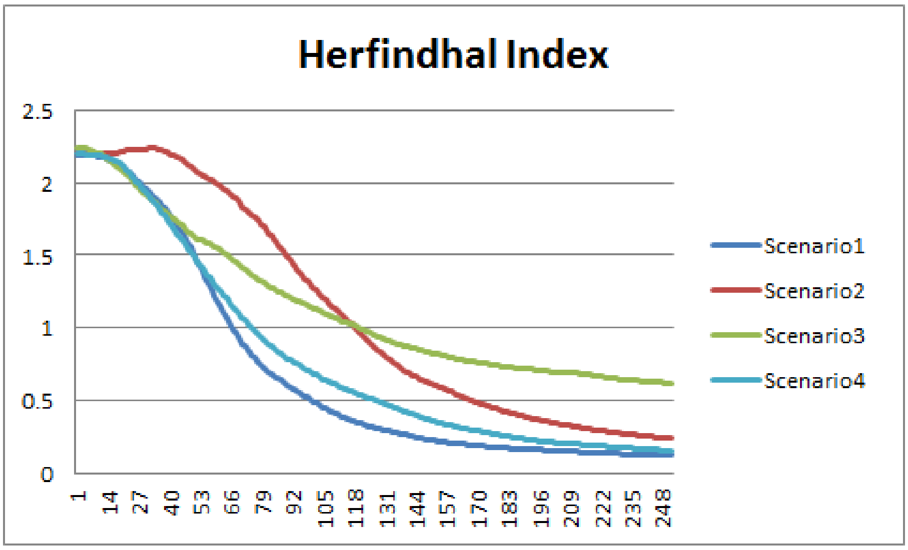

Figure 9: Comparison of Herfindahl index in different scenarios

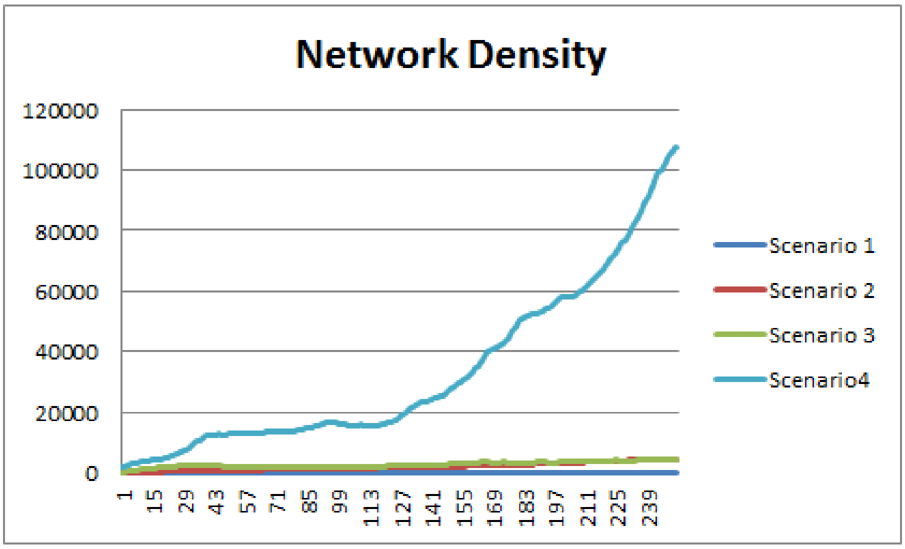

Figure 10: Comparison of network density in different scenarios

CONCLUSION

This paper has a contribution, to extend SKIN framework to use it in modeling real problems by adding absorptive capacity and knowledge spillover features to it. Simulation experiments show that using one partnership strategy at each time (conservative or progressive in basic SKIN model) should be exchanged by absorptive capacity strategy which uses both of them depend on the situation (conservative for less targeted firms and progressive for more targeted firms).

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