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Determinants and Policy Simulation of Firms Cooperation in Innovation

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ABSTRACT

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This research introduces an agent-based simulation model representing the dynamic processes of cooperative R&D in the manufacturing sector of South Korea. Firms' behavior is defined according to empirical findings on the Korean Innovation Survey 2005 and captured in a multivariate probit regression model. The econometrics model identifies the determinants on firms' likelihood to participate in cooperation with other organizations when conducting innovation activities. These determinants are translated into simulation parameters which are calibrated to the point that the simulated artificial world are equivalent to the one observed in the real world. The aim of the simulation game is to investigate the differences in sector responses to internal and external changes, including cross-sector spillovers, when applying three different policy strategies to promote cooperation in innovation. The findings indicate possible appropriate (or non-appropriate) policy strategies to be applied depending on the target industries.

JEL Classification: C15, C71, D21, D85, L20, O31

Keywords: agent-based simulation, collaborative R&D, innovation networks, simulation game, policy strategy

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1. Introduction

Innovation networks have been approached and emphasized in many studies, especially in the evolutionary economics literature. Few works have been done, toward modeling the processes by which these networks are formed and the outcomes of innovative products, processes and firm dynamics. The complexity of the dynamics involved and the heterogeneity of the agents make it hard to model this problem using traditional techniques. In recent years, a new technique using computer simulation through the implementation of heterogeneous and autonomous interacting agents has been used by scholars to model the processes of innovation and technological change.

Agent-based Computational Economics (ACE) tries to break the paradigms and limitations of classical economics through applying agent-based simulation to study the economy as an evolving system of autonomous interacting agents. ACE enables social scientists to conduct "laboratory experiments" to test a theory in computational models that can be easily modified in order to observe the effects on economic outcomes (Tesfatsion, 2001). Agent Based (AB) simulation enhances the capability to analyze theoretical models that, despite their simplicity, are not suitable for mathematical modeling and analysis. Moreover, "the modeler is free to try as many variations as he/she wants" (Zhang, 2003). According to (Axelrod, 2003), simulation is a different way of doing scientific research. It doesn't prove theorems but it generates data to be analyzed inductively which may be used to aid intuition and decision making.

AB simulation has been used among others on models which allowed scholars to have insights about many issues related to innovation and cooperation, such as: impact of knowledge spillover (Haag and Liedl, 2001), emergence and maintenance of cooperative innovation (Beckenbach et al., 2007; Pyka and Saviotti 2000), knowledge spillover and diffusion (Haag and Liedl, 2001; Beckenbach et al., 2007; Gilbert et al., 2001), trust relations among partners (Beckenbach et al., 2007; Daskalakis and Kauffeld-Monz, 2007), innovation timing (Ballot and Taymaz, 1997), etc.

In this research, we are making use of simulation to model cooperative R&D among firms of the manufacturing sector in Korea. Firms are modeled as the agents with heterogeneous behavior. Modeling of firms' cooperative behavior is based on their observable characteristics expressed on questionnaire answers from the Korean Innovation Survey 2005 (Eum et al., 2005). To define firms' behavioral micro-foundations, *i.e.* how firms decide whether to cooperate or not and which kind of partner they would prefer to choose, is the first step of this research.

In recent years, many empirical studies have been conducted based on Innovation Survey Databases. These studies aim to capture impact of agents rationally on the conduction of cooperative R&D (Sung and Carlsson, 2007; Dachs et al., 2008; Heshmati et al., 2007; Sakakibara, 2001; Bayona et al., 2001; and others). Another objective of these studies is to investigate the options and effectiveness of government policies to foster cooperation (e.g. Izushi, 1998; and Katz et al., 1990). The definition of the determinants of cooperation used in the simulation system requires efforts on collecting appropriate theoretical background as well as conducting own econometric analysis on the population data. In designing the econometric analysis we account for theoretical consistency, as well as empirical relevance and use existing literature as a benchmark in evaluating outcomes and our expectations.

We have run several regression analyses in order to extract a reasonable set of factors that could well differentiate the agents on their likelihood to cooperate and on their choice of partner types. In addition, we have applied theoretical background on defining other system's behaviors that could not be extracted from the data. We have also aggregated the Bank of Korea transactions table (Input/output) for the year of 2003 (BOK, 2003) to access information on inter-industry linkages (Midmore et al., 2006).

From the definitions of Agent's behaviors we have implemented the model as social gravitational landscape where firms attract each other based on their individual characteristics, such as size (measured in terms of revenues, number of employees, and R&D intensity); their rationale when conducting or avoiding innovation activities; and the industry they belong to; among others. This attraction would eventually result in firm's interaction which could generate R&D partnership.

The validation of our approach is done by running the model from an empty basic condition (no cooperation in step zero) till reaching a convergence to the quantitative real state of firms in 2004. We have compared numbers distinguished by industry and have tested the accuracy of the number of firms cooperating in the simulated world against the number of firms cooperating in the real world. The equivalent quantitative outcomes obtained helps to validate the accuracy of the simulation model and it allows us to follow to the next step, which is to test proposed policy strategies.

We have tested different policies on different industries comparing them with the actual real state as the starting point. We have run the simulation with policy interventions for an equivalent number of time periods and observed the quantitative outcomes. By comparing the results for each implemented strategy, we can observe, for example: which policies are more appropriate for each specific industry; which industries' policy may impact on network formation in other industries; which industry better benefits by some specific kind of policy; and so on. In sum, the designed policies are industry specific allowing for heterogeneity in level and direction of causal impacts.

R&D cooperation has received great attention among industrialists, decision makers and researchers. It facilitates research collaboration, information sharing, reduced R&D cost, and affects R&D resource allocation, advancement and competitiveness of the national industry, employment and survival of firms. The number of "what if" questions one may apply to this model is virtually unlimited, depending basically on supporting theories, data availability and programming effort. Moreover, the model may also aggregate other types of external agents like government and/or the scientific and institutional systems (Haag and Liedl, 2001; Taylor and Morone, 2005), in order to test other issues which are not supported by the current implementation. These extensions are beyond the scope of this thesis.

From the computational point of view, the techniques used in this work were very sophisticated – going from object-oriented programming to grid and asynchronous teams computing. We made use of java programming to manage the regression grid, which was a set of computers in parallel running STATA routines. Asynchronous nodes generated results for further analysis by a separate agent which, in a search and refine approach, decided for additional regression variations that would be put back on the grid for posterior execution. For the simulation, we used a similar approach but with a much higher number of nodes. About 70 to 90 computers were running different combinations of simulations in order to get the best calibration to the model. The simulation system was fully implemented in Java language and results were stored centrally in an open source database for further analysis.

This basic work is joining microeconomics, econometrics, simulation modeling and computer implementation. The simulation system resulted may be of great help for policy makers. They may test hypotheses and get insights from the artificially generated scenarios in order to test policy hypothesis. We believe that many future improvements and extensions are still possible in order to improve policy makers' ability to identify the best strategies to stimulate firms' innovation cooperation, improving competitiveness and overcoming obstacles of growth and unemployment (Czarnitzky and Fier, 2003) as well as performance and survival of firms.

Rest of this study is organized as follows. In Section 2 we present the literature background about cooperation in innovation and its possible determinants. Section 3 describes the econometrics model and the regression analysis used to identify the cooperation determinants and to specify the cooperation relationships of firms. The simulation model is described in Section 4, while the various policy scenarios and results are discussed in Section 5. In Section 6 we make a brief review of the outcomes from this research. On the annexes, we include some statistical test results based on the simulation results.

2. Literature

This research explores cooperative innovation using a relatively new approach to study social systems, in the context of firms – ACE. Our literature review describes and introduces our rationale to choose the ACE approach, as well as the necessary theory about innovation and cooperative behavior of firms when conducting innovation activities. We also present a set of studies that address innovation process and cooperation in innovation using simulation technique. Since we have incorporated the Korean Innovation Survey we will additionally review previous literature using the same sort of data and utilize the gained experience in the design and analysis of our simulation model and results.

When addressing innovation process, one may not forget to mention Joseph Schumpeter, who introduced a new perspective in economics: the macroeconomic equilibrium is being constantly destroyed by entrepreneurs who, when introducing a successful innovation, forces existing technology to lose their economic position (Schumpeter, 1934). Schumpeter's work fostered the emergence of a neo-Schumpeterian school which created an area named "Evolutionary Economics". Despite controversies if Schumpeter's original work really addressed the evolutionary aspect of economics (Hodgson, 1997; and Witt, 2002), Nelson (1995) states that all theories in this field come with inspiration from Schumpeter.

In regards to cooperative innovation however, Schumpeter observed in his work that the existence of large firms was a necessary condition for innovation. However the unit of analysis has significantly changed in modern times. Cooperative agreements are common in industrialized countries which bring to smaller firms many of the functional aspects of large firms (Teece, 1992). Moreover, today's theories (see Freeman, 1987; Nelson, 1993; Lundvall, 1988 and 1992; Edquist, 2005) define external knowledge, which may be found anywhere on a firm's chain, as crucial for the innovation process, independently of the size of firm. Schumpeterian models are described in Kwasnicki (2003), Nelson and Winter (1982) and Pyka and Fagiolo (2005).

It is well known that innovation is not generated only in the boundaries of a firm or an organization. Firms are not expected to develop all the relevant technologies without accessing external knowledge. Innovation increasingly requires technological, organizational and marketing search involving several players such as firms, customers, suppliers, universities, research institutes, non-profit organizations and so on. Innovation co-operations today are widely considered as an efficient mean of industrial organization of complex R&D processes (Dachs et al., 2008). The sources of valuable knowledge for innovation may be found anywhere on the firm's chain and accessing them may be crucial for firm's competitiveness. The Systems of Innovation approach (Freeman, 1987) shows that competitiveness is becoming more and more dependent on acquisition of complementary knowledge from other firms and institutions. Besides, inter-firm networking and cooperation's importance are emphasized by the increasing complexity, costs and risks involved in the innovation process inside firms.

Profit-maximization driven firms decide to have cooperation alliance with other organizations whenever it brings positive economic return. In the literature, we can find studies showing: the positive economic impact of cooperation on competitiveness of firms (Hagedoorn et al., 2000; Powell et al., 1999; Cassiman and Veugelers, 2002; Belderbos et al., 2004b; Doo and Sohn, 2008) and even on welfare (D'Aspremont and Jacquemin, 1988); the positive impact on innovation performance and knowledge spillover (Miotti and Sachwald, 2003; Czarnitzky and Fier, 2003); and that intra- or inter-firm cooperative competency is a key factor affecting success on the development of new products (Sivadas and Dwyer, 2000). Venturing in cooperative research, however, should be part of firms' innovation strategy. They should create absorptive capacity in order for firms to be able to benefit from external spillovers and increase the associated profitability of R&D cooperation (Cohen and Levinthal, 1990; Cassiman and Veugelers, 2002; Mark and Graversen, 2004).

3. The Simulation Model

For the simulation model in this research, we will initially consider cooperation among firms but we may extend it to include also cooperation with universities, public and private research institutes and non-profit institutions. We will also initially focus on domestic cooperation but we are aware that international cooperation is a relevant extension to this work. Firms may cooperate vertically (with other firms on the supply chain) or horizontally (with firms in another industry or with competitors in the same industry). Cooperation in general is shown as beneficial to firms' performance. However, scholars have found insignificant or controversial results (Knudsen, 2007). In this research, we assume that cooperation in innovation activities will benefit firms in a general way, by increasing innovation output and maximizing economic growth in national level. Thus, we will focus on the ways to maximize productive cooperation among R&D firms.

Determinants of Cooperation

The motivation of firms to engage in cooperation with other firms and organizations has been identified within different internal and external perspectives in fields such as economical, production, organizational, marketing and especially in knowledge sharing and product/process development (Child et al., 2005; Sakakibara, 2001; Wognum et al., 2002; Bayona et al., 2001). We are particularly interested about cooperation among firms on product and process innovation which are directly associated with innovation activities. The main reason that drives any firm's decision is, in fact, the profitability of its business. One question that scholars have been trying to answer is: what are the motivations and characteristics of firms that perform cooperative innovation? Lenz-Cezar and Heshmati (2012) in an econometric approach describe identification of determinants of cooperation for innovation among firms used in this study.

Bayona et al. (2001) performed econometrics analysis on a Spanish database with 1,652 manufacturing firms that have carried out R&D activities. The main findings of this study include: firms perceiving difficulty in controlling *cost* for R&D tend not to cooperate while the ones perceiving *risk constraints* tend to cooperate; *large* firms cooperate more than smaller ones; firms looking to conduct innovation in order to achieve better *quality* of their products tend to develop innovation activities internally; and, those firms in higher *technology intensive sectors* tend to cooperate more than others in lower technology intensive sectors.

Other interesting outcomes regarding to propensity to cooperate may be found in Belderbos et al. (2004a) who applied system probit estimations on data from Dutch Community Innovation Surveys. They tested different equations for different types of partnership. The type of partner chosen by firms for their cooperation activities are positively affected by the *sources of information, firm size, industry average innovative firm size, Organizational capability constraints, risk constraints,* and *speed of technological change*. *Internal knowledge flows* affect significantly and negatively in the supplier equation. Firms belonging to a *group of enterprise* are more likely to cooperate vertically, but not horizontally. *Multinational* firms are less likely to cooperate with competitors. Finally, *R&D subsidy* from the government has a positive impact on vertical and institutional cooperation.

Dachs et al. (2008) studied innovation cooperative behavior analyzing data from CIS-3 in Finland and Austria. Even though the rates of innovator firms in both countries are similar, the rate of cooperative firms in Finland is considerably higher than in Austria. Their findings are not really conclusive. Basically, only two factors have the same impact on cooperation for both countries: companies that received funds from European Union tend to cooperate, and also the ones considering universities and research institutions as important *sources of information*.

Mark and Graversen (2004) analyzed Danish data containing 592 observations of innovative firms where 63% of them developed some sort of cooperation. They showed that: firm size affects positively domestic cooperation; if firms employ *foreign* people they tend to cooperate more with international organizations; R&D cooperation is more common to those firms *conducting* innovation *process*; the existence of an *R&D department* and the presence of *skilled researchers* also affects positively the probability to cooperate; the ratio of *R&D expenditure* and the ratio of *R&D employees* increase the probability of cooperation. For the negative factors, the authors found two sectoral determinants: *market concentration* and higher *profitability*.

Miotti and Sachwald (2003) also confirm that firms in *high-tech* sectors tend to cooperate more than the ones in *low-tech* sectors, however, cooperation with rivals are associated mainly with *high-tech* sectors while institutional and vertical cooperation are more concentrated in *low-tech* sectors. Results in Belderbos et al. (2004a) also indicate that belonging to a *group* of enterprises affects positively vertical cooperation.

Sakakibara (2001) analyzed government supported R&D cooperative projects in Japan. Among several findings the ones related to our model include: firms in R&D-intensive industries cooperate in order to enter other R&D-intensive industries; firms tend to conduct cooperative R&D projects in vertically related industries with forward and backward links; firms in profitable or oligopolistic sectors tend to cooperate in R&D projects in industries with higher growth rates than their own industries.

Innovation Networks

The definitions and varieties of networks in innovation are broad and range from Porter's (1998) concept of geographically established clusters to worldwide standardization research consortiums. They can be formally established on contract basis as outsourcing relationships and strategic alliances, but they may also rely on informal ties like membership of an industry association. Networks may be based on long term relationships or last just for the duration of a short-term joint project. As regards to its organization, it may be governed by a central institution as well as have some sort of distributed self-organization. Excellent conceptual studies about networks, their structure, characterization, role, and governance are found in Powell and Grodal (2004) and Hamdouch (2008).

National Systems of Innovation, originally defined by Freeman (1987) as the "*network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies*", have been widely adopted as a theoretical framework for policy making. The Systems of Innovation approach describes networks as the conduits for the exchange of knowledge among players. In their inspiring book addressing innovation networks and simulation, Küppers and Pyka (2002) define innovation networks to be "*interaction processes between a set of heterogeneous actors producing innovations at any possible aggregation level*".

By networking, firms constitute a channel to receive and transmit knowledge flows to and from other firms. The exposition of firms to new sources of knowledge contributes significantly to their innovative capacity. In addition, there are also other benefits that networks may offer, such as *economies of scale* reducing individual firms' costs of innovation; *economies of scope* arising from complementary expertise; and, *risk sharing* from innovation activities (Boekholt and Thuriaux, 1999). A wide range of academic studies and governmental reports point networks of firms as crucial condition for innovation and economic development, in particular where the market structure is predominantly composed by small and medium enterprises.

Even though the benefits of networks and clusters are clear, there are also a number of barriers for the formation of networks such as: *lack of awareness as to the benefits of networks; reluctance to commit time and resources to a process that is not well understood; reluctance to share information and knowledge with other firms; firms are not always well placed to identify the opportunities for network relationships; and a group of individuals or firms may frequently fail to achieve co-operation*" (Forfás, 2004). Governments must be aware of the barriers and play a major role on fostering and creating conditions for network formation. This may be done in many ways: from promotion of firms' interaction to financial and organizational support. Boekholt and Thuriaux (1999) point out a set of roles from public policy to counter the "*system deficiencies*" that hamper the formation of clusters and networks.

Policy Initiatives

Since the importance of networks had grown considerably over the last decades, policies have been conducted by governments worldwide in order to create and nurture cooperation networks. Good examples of network cases are:

Italian Industrial Districts (Pyke et al., 1990) – The Italian districts are some sort of regional/sectoral systems of innovation aggregating SMEs, research institutions and trade associations in northern Italy. Organized government co-operatives made possible that those small companies, in traditional industries could compete effectively with large and well established enterprises worldwide.

Danish Networks Programme (Pyke, 1994) – Government funds supported networks composed by 3 or more companies co-operating. More than a hundred networks with more than 500 small firms received micro-grants from the government to test feasibility of the network. This program has been pointed as responsible for the dramatic turnaround in the Danish economy.

Norway Horizontal Networks (Amphion, 1996) – this program focused on horizontal networks. In the first phase, 730 networks were formed. In the second phase, the government added support to verticalized networks adding 340 more networks to the program. The success in Denmark and Norway stimulated some other countries to develop similar policies.

UK Virtual Centres of Excellence in Mobile Communications (Vaux and Gilbert, 2002) – This sectoral network was set in 1996 with the participation of 7 universities and more than 20 companies in the mobile phone industry. The maintenance of the network was supported by both government and corporate funds from its participants pointed as one of the indicators of the success of this initiative.

Japanese Engineering Research Associations (ERAs) (Sigurdson, 1998) – is pointed as the Japanese effort to catch-up western countries. They were institutional arrangements to promote collaborative R&D between companies. A successful case is the Camera Association enabling brand names like Nikon, Canon, Olympus, Konica and Fuji Film to become global players. The Japanese ERAs represented a great effort towards development of an innovative environment (Sakakibara, 2001).

European Community's policies had to deal with the perceived loss in competitiveness in the global environment as well as with the disparities among wealthy and less developed members in terms of S&T infrastructure. The framework programs – the instrument for S&T policy in European Union – established as a prerequisite to support joint research in which at least two member countries were represented by the agents. The budget for R&D centralized in the European Commission represents only a fraction of the total budget of member countries. In fact, each country runs its own policy and develops its own instruments to foster cooperation.

Government policies towards cooperative innovation are not limited to actions to put together related companies and research centers. The US policies in the early 80s, included extensive changes on regulation of intellectual property rights and antitrust to accomplish the new international competitive environment. (Hagedoorn et al., 2000)

Agent-based Simulation

As pointed by Pyka and Fagiolo (2005), the current computational power has led to massive use of numerical approaches. In economics, there seems to be a broadly shared view that linear analysis offered by neoclassical economics could reach the necessary level of accuracy and elegance. Moreover, there is also a general position that "*computation is unnecessary, since mathematical methods are not only preferable, they are almost always applicable*" (Miranda, 2005).

Agent-based Computational Economics (ACE) tries to break these paradigms through applying agent-based simulation to study the economy as an evolving system of autonomous interacting agents. ACE is an acronym first used by Tesfatsion (2001) to refer to agent-based modeling in economics. It enables social scientists to do "*laboratory experiments*" to test a theory in computational models that can be easily modified in order to observe the effects on economic outcomes. See also Zhang (2003).

Economy is suggested to be a complex system composed by interacting agents whose aggregation generates a number of macroeconomic phenomena which are difficult to explain with standard models (Kirman, 2004). In Novarese (2003), the author argues that simulations should be performed in parallel to traditional mathematical models.

ACE is composed by elements from computer science, economics and the social sciences. These elements are combined in a simulation system in order to study artificial societies in a bottom-up approach. The main ingredients of ACE models are (Fagiolo et al., 2007; Tesfatsion, 2001; Richiardi, 2007): *Heterogeneity* – There is no aggregate level representation of entities; *Autonomy* – There is no centralized control over individual agent behaviors; *Bottom-up perspective* – use the principle that aggregate properties result from the dynamics of basic entities; *Bounded Rationality* – Agents are not perfectly rational and they cannot see the system in a whole; *Interactions* – there is a network structure connecting the agents, not necessarily and uniquely by geographic proximity; and *Non-equilibrium* – ACE models do not obey a one-shot game, where scholars observe the beginning and the end state of the game.

According to Axtell (1999), AB models may be used in different ways: as a type of *Monte Carlo simulation;* as a *Tool for Presenting Mathematical Results* under different conditions. Thus, ACE models may be used in a "*complementary way*" to mathematical analysis or even as a "*substitute*" way going beyond formal models allow us to go.

The evolutionary approach of systems used in ACE is not new. The new thing about ACE is the use of modern computational techniques. One of the direct applications is the implementation of ABS systems. In this work, we make use of computer science techniques – the Object-oriented approach to describe, model and implement the simulation. Java is the best choice of language. It has been used on the development of many frameworks and libraries to be applied in agent-based simulation. Moreover, due to its modernity, it has been object of great development in computer science.

We have observed that ABS implementations described in the majority of papers available, are of extreme simplicity for the computer science point of view. In fact, the computational models are relatively simple and their implementation also easy (Axtell, 1999). IT professionals are used to develop applications with much more complexity. We understand that the most difficult parts of the job would be gathering the required theory to sustain the assumptions of the modeled behaviors, and the fine tuning necessary to make simulated numbers accurate to realistic situations. From the computational point of view, the implemented AB systems are still at an infant stage.

AB Simulation in Innovation Networks

About studies of the economics of innovation and technological changes, Dawid (2005) argues that ACE is a well suited technique. Dawid surveys a considerable set of works related to simulation and innovation, starting with a pioneering simulation study about the interplay of industry evolution (Nelson and Winter, 1982) and going through: analysis of technological spillovers in a dynamic heterogeneous oligopoly model (Cantner and Pyka, 1998); modeling how firms conduct R&D (Cooper, 2000); heterogeneity of innovation strategies (Llerena and Oltra, 2002); among other themes.

The capability of agent-based models to capture dynamics and complexity is exactly what is needed to study firms' cooperation and innovation networks formation (Taylor and Morone, 2005). An entire set of studies were made apart from neoclassical theory (Gilbert et al., 2001; Pyka and Saviotti, 2000; Albino et al., 2006; Beckenbach et al., 2007; Taylor and Morone, 2005; among others) emphasizing the use of simulation with ABM to investigate interactions between firms when conducting innovation activities.

Beckenbach et al. (2007) investigated the behavioral foundation of agents, in regional level, when deciding to conduct innovation. They conducted a survey in a region of Germany with 527 respondent firms. These data were used to calibrate the behavioral parameters in the model, basically using factors extracted from empirical findings. Among the calibration parameters, there were also others not related to the survey.

Daskalakis and Kauffeld-Monz (2007) conducted an investigation using ABS to study the dynamics of trust building in regional innovation networks. They also conducted econometrics analysis over 23 innovation networks. With the regression analysis, they proved the relevance of trust, its inter-relationship with knowledge exchange, and trust building mechanisms. From the empirical findings, they constructed and calibrated the agent-based model in order to simulate the dynamics of trust and knowledge transfer.

Three authors who are very active in innovation networks research area have long been working together investigating innovation networks with agent-based models (Pyka et al., 2001; Gilbert et al., 2001; Ahrweiler et al., 2004; and Pyka et al., 2007). There are also additional working papers that may be easily found when one attempt to search studies that address innovation networks and agent-based simulation.

Few researches follow the concept of "*KENE*" introduced by Gilbert (1997) – some sort of genetic representation for knowledge. KENEs are triples of numbers containing information of the agents in 3 elements (capability, ability and expertise) that may be exchanged between companies. The agents search for new products which are generated from their KENEs and they need innovation in order to survive in the market. Firms look for external partners in order to exploit external knowledge source.

Gilbert et al. (2001) implemented their model for two real cases of networks: Mobile and Biotech, both described in Pyka and Küppers (2002). The calibration process was conducted by experimentation on the ranges of values in order to get reasonable results. The two simulations used 30 and 40 imaginary agents respectively. The outcomes were considered qualitatively satisfactory by the authors even though there are considerable differences between the artificial world and the real worlds.

Pyka et al. (2007) included some firm dynamics in the model which allowed the creation of new start-up firms based on successful ones. An additional evolution is that networks are also treated as agents and they must contain 6 or more agents. Again they also set the model to run with imaginary firms – 500 agents in the initial state. They played the simulation game in a "*standard scenario*" and in 7 modified scenarios.

Pyka and Saviotti (2000) developed a model to investigate innovation networks in the biotechnology sector. The model attempted to represent the roles of two types of firms on network formation: large diversified and dedicated firms. They run the model for 12 imaginary firms and compared the artificial network with some existing database in order to observe network structures. They found regularity on peaks over time but with completely different orders of magnitude.

Albino et al. (2006) developed an agent-based model to simulate the process of innovation in an industrial district. The entities in the model interact with each other in different types of links. From these interactions firms enroll in a learning process. The simulation is run with 8 final firms, 16 suppliers, and 4 infrastructure suppliers. Four different scenarios were tested. The analysis attempted to observe firms' survival and profitability to judge necessary adjustment on industrial districts.

Taylor and Morone (2005) deal with proximity for partnership formation in the province of Foggia in Italy. They conducted a *focus group* with a chosen sample of 32 firms and 16 supporting institutions, in order to capture network formation, agents rationally and benefits. The simulation model main objective was to verify the role of institution on network formation and innovation dynamics.

Despite the great advancements made by ACE researchers toward theoretical and computational infrastructure, ABM models have long been neglected by the main stream of economists. There is a general skepticism which reflects on the number of publications of ABM articles in first grade journals (Leombruni and Richiardi, 2005). In reality, it seems to exist a prejudice against computational economics in general (Miranda, 2005). The ABM community has its counter-argument against these criticisms. We will accept the methodology as valid to address the issues we want to address. Agent-based Simulation of cooperative innovation in R&D used in this study is further explained in Heshmati and Lenz-Cezar (2013). For further readings about raised methodological issues in ABM, one should refer to Axelrod (2003), Novarese (2003) and Pyka and Fagiolo (2005).

4. Policy Scenarios

Here we will discuss about the extension of our simulation model to accomplish future scenario analyses. We already have discussed about the validation of the model on capturing industry differences in terms of number and percentage of firms cooperating. The model was calibrated in order to get the lowest difference between the percentage of firms cooperating in the real and the artificial worlds. The approach we used considered aggregated data on industry SIC 2-digit level.

As discussed before, many of the firms cooperating in the virtual world were not cooperative in the real world. These firms have, in fact, strong willingness to cooperate according to the determinants of cooperation and there is no specific characteristic that could discriminate them from regular cooperative firms. On the other side, there are also firms that cooperate in reality but the simulation exercise did not found them to cooperate in the artificial world. Even though these firms cooperate, their characteristics are very similar to non-cooperative ones. There is a great potential for increasing the number of cooperative firms in Korea. Our approach on this phase of the simulation exercise attempts to explore this remaining potential to cooperation.

During the first step, we started the simulation with zero number of cooperation and run the system up to the point where the number of cooperative firms in the virtual world was equivalent to the corresponding number in the real world. On the final calibration set the simulation was performed through an average of 65 time periods or steps. In order to explore the remaining potential for cooperation among firms, the new approach starts the simulation game with the firms identified to be cooperating in the innovation survey. Then, the simulation is run for some number of steps with the objective of observing the outcomes in terms of additional number of cooperative firms. This is done at first with no intervention from "governmental policies" in order to generate a reference scenario to be compared with the policy scenarios. Next it is run the same number of steps but with some policy intervention. The results are then compared with the reference scenario and the differences between industries are further analyzed.

When firms establish cooperation with each other, it does not mean exactly that they have created a network. By networking, firms expect to constitute a channel to receive knowledge from other firms. We cannot address any formal concept of Innovation Networks (Cooke, 2002; Hamdouch, 2008) since we have no data about their structures. Besides, "*The notions of "clusters" and "innovation clusters"are far from being unified and grounded in solid analytical frameworks*" (Hamdouch, 2008).

In our model, each set of N linked firms is treated as a network. Pyka et al. (2007), for example considered networks to be composed with a minimal of 6 firms. The Danish Networks Programme (Pyke 1994) considered any link with at least 3 firms a network. In our case, networks are formed when at least 5 firms cooperate with each other. Networks can merge to each other when two firms from different networks decide to establish new partnership. It is considered that knowledge flowing from one partner to another, in certain ways may also be available to a third partner. The identification of the industry to which a network belongs is by the industry with the majority of firms participating in the network. Networks in our simulation model emerge in a completely spontaneous way, i.e. there is no instrument driving their creation and coordination.

From the sample of 1,839 firms, there are a total of 359 cooperative firms, as identified from their answers in the innovation survey. The initial setting of the simulation requires that these 359 or, at least the majority of them, cooperate with some other firms from the same sample. In general, it is not possible to find suitable partners in the existing landscape for 100% of the 359 cooperating firms. An average percentage of 19% of the firms are left without any cooperation due to incompatibility to the existing available potential partners. It is assumed that these firms would be cooperating with firms outside the current sample.

The initial landscape (see Figure 1) was populated as an approximation of a possible actual scenario, considering the population of firms available in the innovation survey. An interesting extension to this work would be to compare this artificial generated network with the existing one found in reality. It should be noted that each simulation run may generate a different initial landscape due to the random placement of firms.

For this reason, the final results are calculated from the mean values of a number of simulations. We also run some t-tests in order to verify statistical similarities on the means.

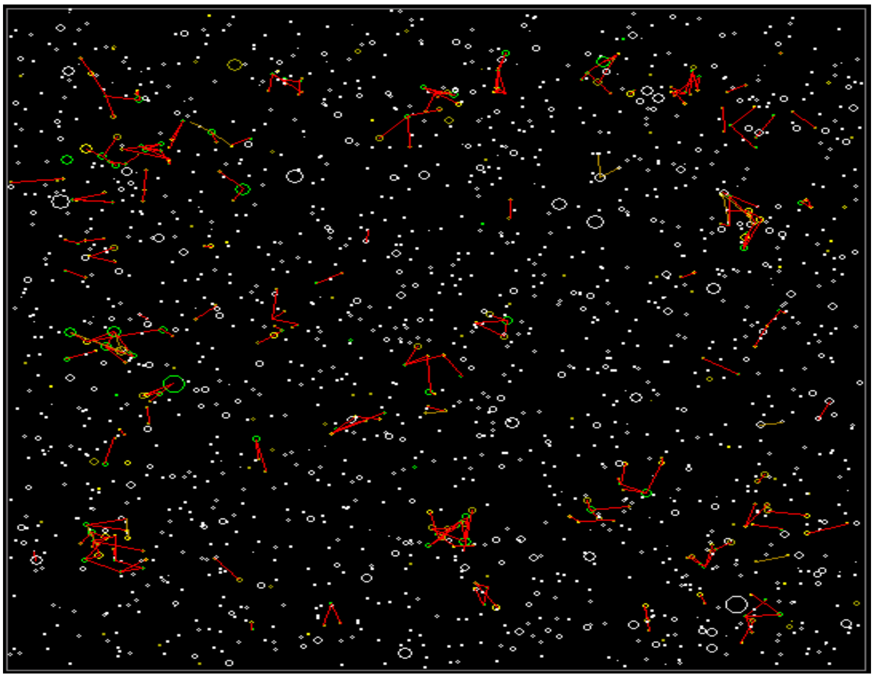

Figure 1. Starting point with real cooperating firms

4.1 No-policy Scenario

Once firms are placed in the landscape and their matching partners are linked, the simulation game plays for a number of steps without any changes in the environment. The artificial world is a shrinking universe with firms tending to concentrate at some part of the landscape if the execution is not stopped at some point. We have found 50 steps to be an optimal ending point, since it is long enough to allow us to observe the impacts of policies without the distortions provoked by a long game.

In a no-policy scenario it was considered that the current actual cooperative state of firms is not in balance and that they would naturally develop more and more cooperative links when time goes on. Firms enroll in joint partnership but they also exit from these cooperative projects at some point of time. For simplicity of the model, we have not implemented the destruction of cooperative links. We observe only network formation and not the destruction or maintenance of these links. Our study uses the same strategy as Taylor and Morone (2005). Some examples of models addressing the full dynamics may be found in Albino et al. (2006) and Gilbert et al. (2001).

Figure 2 is a snapshot of the result of the simulation game in a no-policy scenario evolving from the initial state in Figure 1. It is possible to observe the emergence of bigger networks as more steps were added to the simulation game. The numerical results for the no-policy scenario compared with the results found in the final calibration set can be visualized in Figure 3 and Table 1.

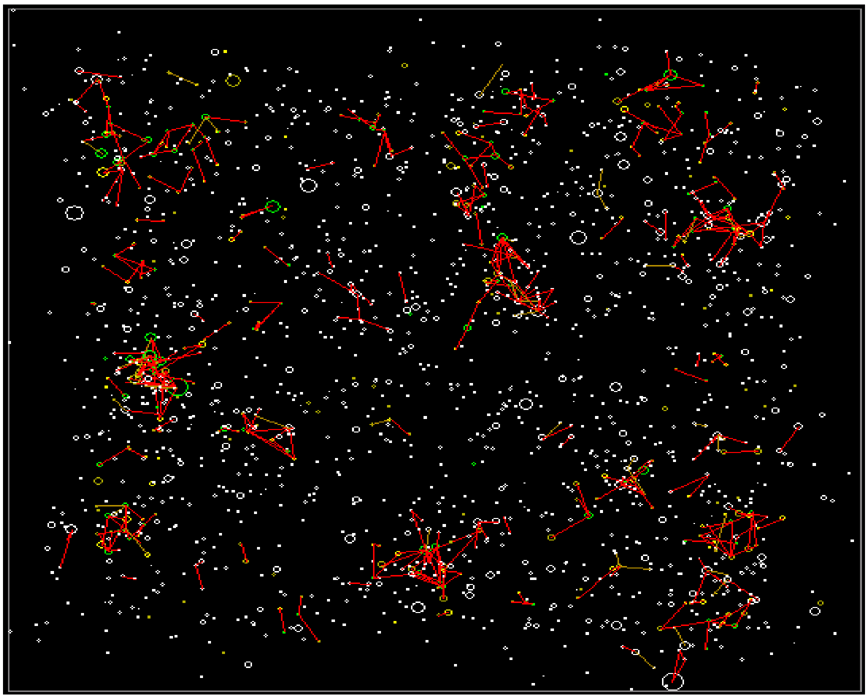

Figure 2. Final landscape with no policy intervention

Table 1. Presents the result for the industries with more than 100 firms, which will be the focus of our analysis in this chapter.

Table 1. Results in the final calibration simulation and no-policy scenario

		Real			No Policy Scenario			
	Industry	Number of Firms	Firms Cooperating	Firms Cooperating (Calibration)	Firms Cooperating	Firms Networking	Sum of NetCoopAvg	Cooperation Growth
+ 100	A [29] Machinery & Equip(M)	255	49	51	73	57	78%	49%
	B [24] Chemicals(H)	218	52	51	77	54	70%	49%
	C [32] Electronics & ICT(H)	184	36	43	59	41	70%	64%
	D [31] Electrical Machinery(H)	147	24	30	37	20	54%	**55%**
	E [15] Food(L)	137	19	24	31	14	44%	64%
	F [34] Vehicles(M)	132	34	38	53	32	**60%**	**56%**
	G [28] Metal Prod(L)	120	23	19	30	22	74%	30%
	H [25] Rubber & Plastic(M)	113	17	15	24	15	**61%**	41%
+100 Total		1306	254	271	385	255	66%	52%
+50 Total		273	53	58	78	43	55%	47%
-50 Total		260	52	33	56	29	52%	7%
Grand Total		1839	359	362	519	326.9	63%	45%

For half of the industries, the ratio of the number of firms networking over the number of firms cooperating is quite high (over 70%), meaning that most of the firms which decide to cooperate are doing it in a selected group of firms. We may not ensure that this is exactly true, since this is just a "prevision" game. Nevertheless, we believe that the numbers at least show trends. For example, the results point to the fact that it is very likely that the ratio of firms networking on the Food industry would be lower than in Rubber & Plastic in reality.

We have also conducted t-test to check whether different means are statistically different from each other (numbers in bold are statistically equal at the 5% level of significance). We found that in the ratio of firms networking, industries SIC-25 and SIC-34 have equivalent values indicating similar cooperation growth pattern. For impact of the no-policy scenario on the number of firms cooperating the means of industries SIC-31 and SIC-34 have statistically the same cooperation growth rates. The equalities are confirmed by the statistical equivalence of the means.

Another interesting observation from the results reported on Table 1 is that industries SIC-15 (Food) and SIC-32 (Electronics and ICT Equipment) appeared as the industries with greater growth potential among the cooperative firms. Industry SIC-28 (Metal Products) presented the lowest cooperative potential.

As it becomes evident in the presented results in Figure 3, the number of firms cooperating sometimes is really low even for the chosen "+100" industries (17 firms for SIC-25, for example). Adding or dropping one firm in the result set may cause variations over 5%. This is the reason why we have selected only the set of the 8 larger industries to be part of our analysis. It must be noted that numerical variations may be large and cause distortion to the final result.

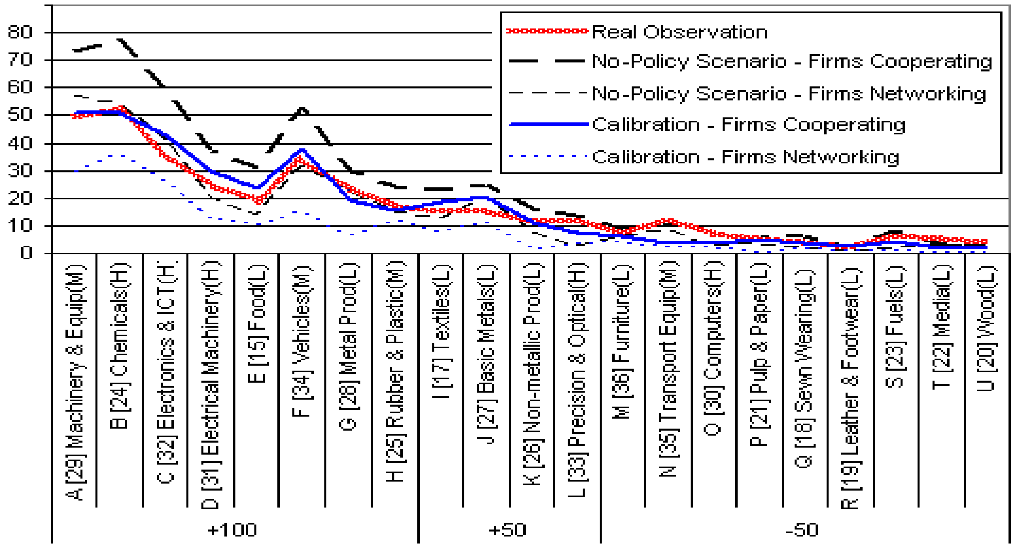

Figure 3. Number of firms cooperating and networking

4.2 Policy Scenarios

The policy game starts with the landscape being populated by the firms in the same way it was done in the stage of calibration. Then, firms cooperating in the real world are linked in partnership with each other in a search process that guarantees firms matching. At this point, the landscape represents the current situation of firms and it is the same starting point of the no-policy scenario presented (Figure 4). Next we introduce the policy instrument, and run the simulation for some 50 steps. Each policy instrument is run for a specific industry, among the 8 larger industries (SIC 15, 24, 25, 28, 29, 32, 32 and 34). The objective is to observe how different policies may produce different outcomes across industries. We also would like to observe the heterogeneous impacts that some policy may have on industries and attempt is made to attribute the differences to observable characteristics of the industry.

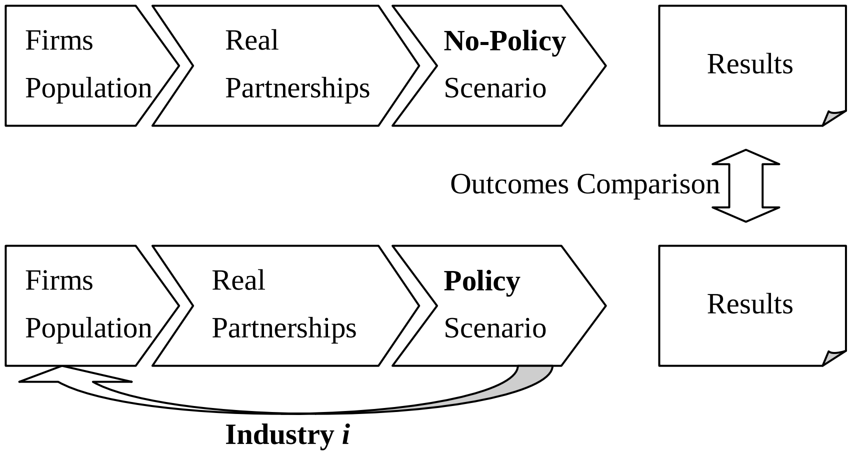

Figure 4. Policy scenario simulation

The meaning of applying certain policy instruments varies with the different concepts of the policy introduced and it may positively impact on the firms' willingness to cooperate, better attractiveness to cooperation or even desired concentration in certain area of the landscape. In this research, we implement 3 different policies using 4 different abstractions. Although it is possible to imagine and introduce much more different policies, we leave that as possible future extensions of this research.

It is important to mention that we have not taken into account any current policies toward cooperation being applied in Korea when the current scenario of firms' network was created. We assume that either the policies defined in this research are not being applied, or they are not effective. These additional effects are what we want to capture with the simulation exercises discussed above.

4.2.1 Clustering policy

Our first scenario addresses one of the main policies that governments use in order to develop certain industries and regions. There are many examples of cluster policies worldwide and a representative set may be reviewed in Roelandt and den Hertog (1999). Clusters are usually related to Porter's (1998) concept of geographically established networks of institutions and firms vertically integrated in some particular field. Innovation clusters must also include actors other than industries and be formed based on market principles but also strongly inducted by governments.

Korea is well known by the conception and implementation of industrial complexes policies taken place throughout the country since the early 60s. These policies started in 1962 with the Ulsan-mipo complex where the government planned the placement of motor vehicles, ship building and chemical industries. This strategy persisted for the following decades and the *Chaebols* emerged from, and were also responsible for, the creation of new clusters. Not so long ago, the country had not been so successful in its attempt to shift its production clusters to innovation clusters in large scale. The lack of success is mostly due to regional imbalance where: most of the S&T system and business activities in Korea are concentrated in Seoul and its surrounding areas (Lee, 2001). Nevertheless, Korea is a small country and firms may easily access and relate to other organizations with much lower cost.

In the KIS-2005 database we grasp that, even though there may exist some regions with high concentration of firms from certain industries, the analysis at the SIC 2-digit level shows that there are no regions out of Seoul and Gyeonggi-do that concentrate more than 20% of the companies in one industry (Table 2). The most evident cases outside the capital city area are Gyeongsangnam with 20% concentration of firms from industry SIC-29, and Ulsan, where the "Motor Vehicles" industry (SIC-34) has twice larger number of firms than any other industry located within that region.

Table 2. Concentration of firms for each industry (by region)

	A [29] Machinery & Equip(M)	B [24] Chemicals(H)	C [32] Electronics & ICT(H)	D [31] Electrical Machinery(H)	E [15] Food(L)	F [34] Vehicles(M)	G [28] Metal Prod(L)	H [25] Rubber & Plastic(M)	Other Industries	Grand Total
Seoul	7%	29%	19%	10%	19%	5%	5%	6%	21%	16%
Busan	6%	5%	3%	7%	4%	4%	9%	6%	8%	6%
Incheon	12%	5%	11%	9%	3%	8%	12%	7%	7%	8%
Daegu	5%	1%	2%	3%	1%	8%	5%	5%	5%	4%
Gwangju	2%		0.4%	2%	1%	1%	1%	3%	1%	1%
Daejeong	2%	2%	2%	1%	3%	1%		1%	2%	2%
Ulsan	2%	3%	0.4%	1%		**6%**	1%	1%	3%	2%
Gyeonggi	33%	29%	38%	38%	22%	25%	30%	30%	22%	28%
Gangwon		1%		1%	4%	1%	2%	2%	1%	1%
Chungcheongbuk	3%	5%	5%	6%	7%	4%	4%	9%	3%	4%
Chungcheongnam	4%	6%	4%	9%	10%	11%	4%	6%	3%	5%
Jeollabuk	1%	4%	2%	1%	4%	2%	1%	2%	3%	2%
Jeollanam		2%			4%	2%	2%	2%	3%	2%
Gyeongsangbuk	4%	2%	9%	4%	8%	10%	10%	5%	8%	7%
Gyeongsangnam	**20%**	6%	5%	6%	10%	14%	13%	15%	10%	11%
Jeju					1%		1%		0.2%	0%
Grand Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

The abstract representation of this policy in our simulation model consists of creating a gravitational field in part of the landscape that exerts strong attraction on firms belonging to the target policy industry being addressed. For example, Figure 5 displays clustering policy being applied to industry SIC-32 (Electronics and ICT) on the left upper side of the landscape. Firms which are outside the delimited area will be attracted to some point within the circle and will not be attracted by other firms before reaching a minimal distance from that point. The effects of the attraction are felt only by firms from the sector being addressed.

The abstraction in this model would be some public policy that would shorten the "social" distance between firms from certain industry. The effects expected from this policy include the increase on the number of firms cooperating and networking. It is also expected that there will be an increase on the size of the networks and a consequent reduction on the number of networks due to merges between networks.

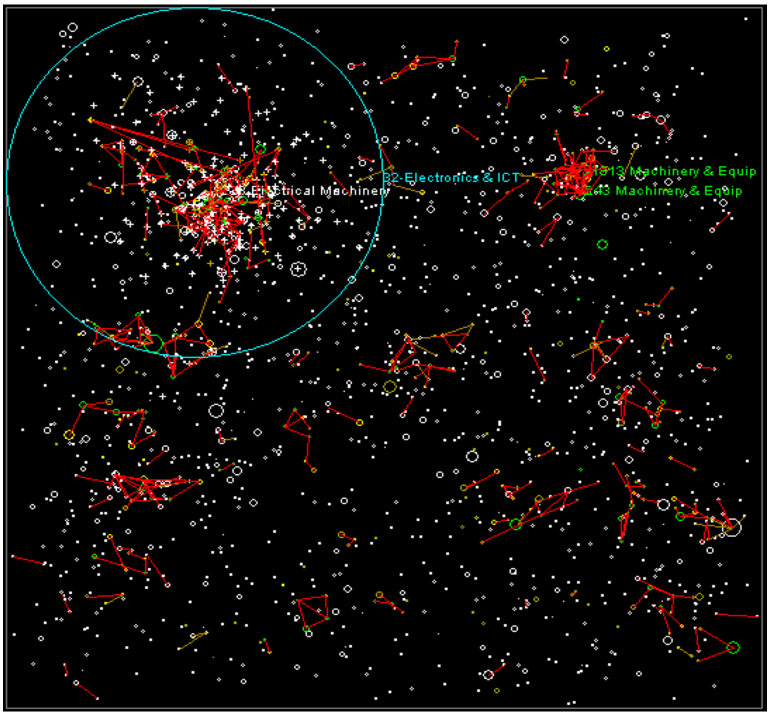

Figure 5. Policy Scenario 1 for industry SIC-32

The obvious outcome from applying the concentration policy for certain industry would be in form of direct growth on the number of firms cooperating. Observing the impact of the policy over the industries (Figure 6), we find that this is true for every industry, except industry SIC-25 (Rubber & Plastic). The policy does not work for this industry, which has a negative effect on the number of firms cooperating. The Food industry (SIC-15) is found to be the one with greater impact. There is sufficient evidence that this policy when applied to industry SIC-31 would produce lower impact than when it is applied to sector SIC-32. The Rubber & Plastic industry suffers a negative impact when the policy is applied to industry SIC-24 (Chemicals). This shows evidence of a cross-sector effect, namely, that a policy targeting one sector may affect other sectors.

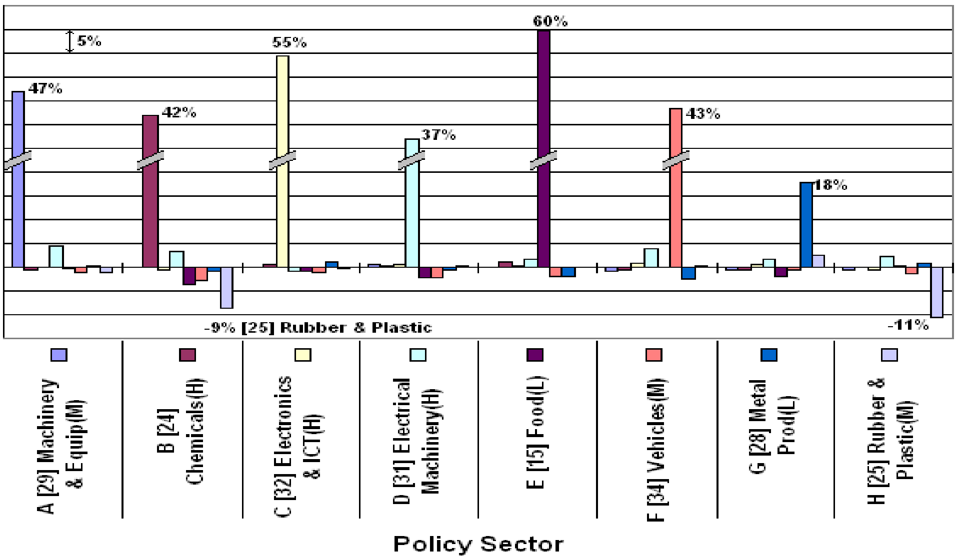

Figure 6. Impact on the number of cooperating firms (clustering scenario)

In Figure 7 we present the effect of the policy on the number of firms networking. The Food industry exhibits a much higher impact when compared to other sectors. It may also be observed the cross-sector effect on Rubber & Plastic when policy is applied to Chemicals. Moreover, there is also an impact on industry SIC-31 (Electrical Machinery), which originates from application of the policy on Vehicles industry. There is no statistically significant difference between industries SIC-31 and SIC-32; and also between SIC-32 and SIC-34.

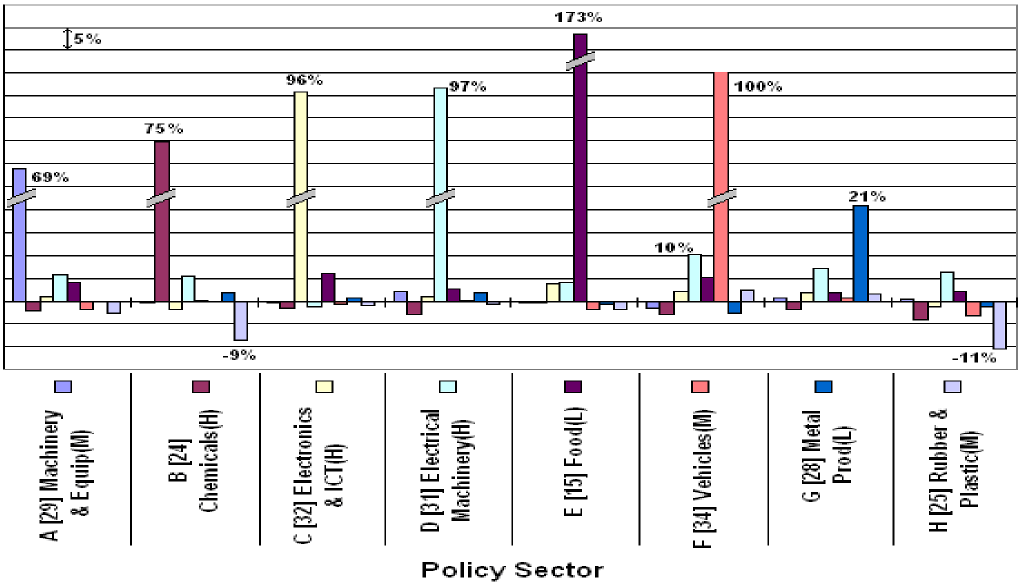

Figure 7. Impact on the number of firms networking (clustering scenario)

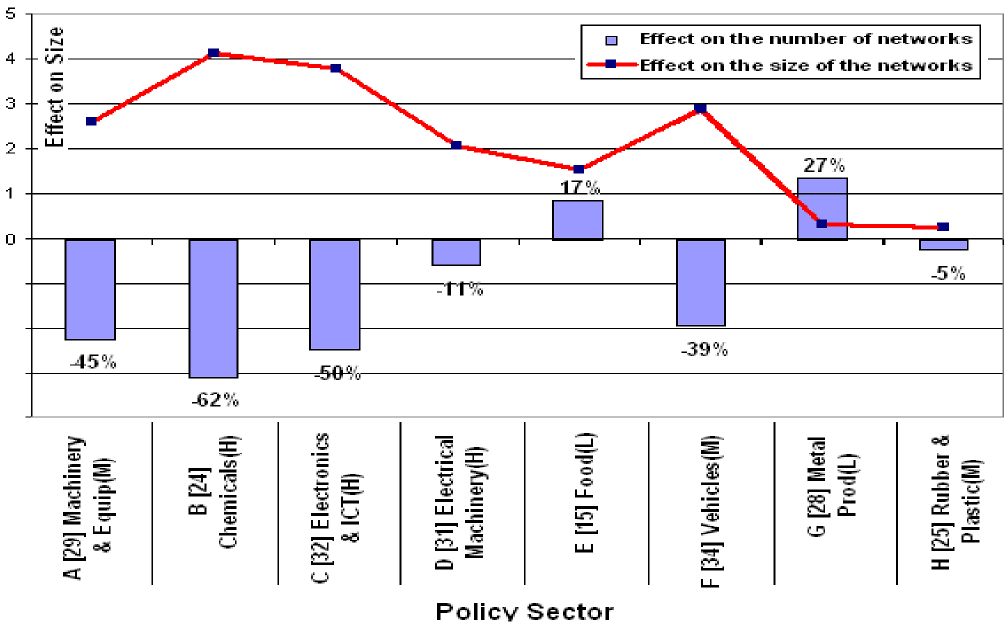

Figure 8. Impact on the size and number of networks on the policy sector

The results in terms of the number of networks on the policy sector are compatible with our prevision that more concentration would impact negatively on the number of networks. This is due to the high concentration which would lead to higher number of merges. On the other hand, a lower number of networks and a higher number of firms networking implicates automatically on the increase on the network sizes. Figure 8 displays the effect on the average number and size of the networks from the sectors being addressed by the policies. It is interesting to note that in the Food sector, both size and number of networks increases.

This type of policy may be understood as a cluster policy where firms from one sector get close to its peers from the same sector. A higher concentration means an increasing number of interactions among firms and cooperating with each other. It worked this way for all industries, except for the Rubber & Plastic industry. This unexpected outcome might be due to the way the model implementation was conducted could have caused some sort of bias on the simulation dynamics. Industry SIC-25 is the industry with lower number of companies. Initially, we set the circle representing the sector area with the same size, independently of the industry type. As a consequence, bigger industries are more concentrated than the smaller ones. Nevertheless, running the same policy with half of the area confirmed that the decreasing effect still persisted.

A possible answer to the negative effect when analyzing in which type of partnerships the firms in sector 25 were engaging. Figure 9 shows the number of partnerships between firms from industry 25 and other industries. Except for the line representing industry 25, which means intra-sectoral partnerships, all other lines are representing cross-sector partnerships. The majority of partnerships are inter-sectoral and in 28% of the partnerships both firms belong to industry SIC-25.

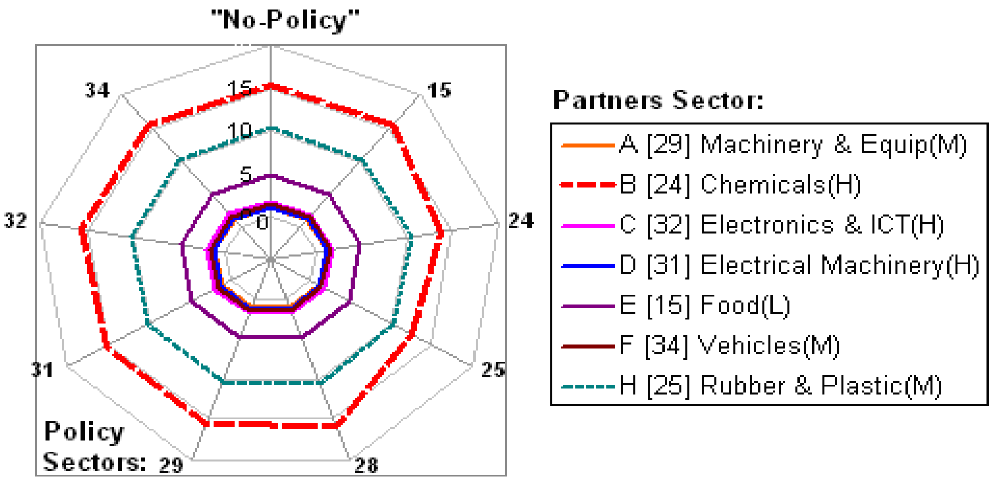

Figure 9. Partners industries relating to industry 25

From the point of view of commercial transactions between these sectors, Chemicals is responsible for 48% of all inputs to the Rubber & Plastic industry. This is equivalent to 9% of the whole demand of Chemicals in Korea. That makes the relationship between Chemicals suppliers and Rubber & Plastic customers mutually attractive. From the point of view of Rubber & Plastic, Chemicals suppliers are even more attractive than suppliers in the same sector. In addition, the Chemicals industry also consumes 3% of the production of Rubber & Plastic which is significant to allow a minimal level of attractiveness from Chemicals customers. Moreover, firms on Chemicals industry have more willingness to cooperate than firms in Rubber & Plastic.

Figure 9 shows that when the clustering policy is run for industries SIC-24 and SIC-25, there is a decreasing number of partnerships between firms from these two sectors. If firms from one of these sectors concentrate in certain region on the landscape, that means they will be generally distant from most of the firms from the other sector. We can also observe that the number of partnerships with other industries remain stable independently of the sector where the policies have being applied. A deep look on the innovation survey data for industry SIC-25, we found that firms cooperate more with suppliers than with customers or competitors.

In regard to the large policy effect on Food industry SIC-15, we found this industry to be not integrated with any other industry. Fifty-one percent of SIC-15 output has the consumers as final users; 30% goes to other sectors like agriculture, fishing and service sector; and 13% is directly sold to firms in the same industry. For its inputs, 69% does not come from the manufacturing sector and 20% originates from the same industry. The number of intra-sectoral partnerships is much higher than the number of inter-sectoral partnerships. Another industry with similar characteristics in the output is industry SIC-31 (Electrical Machinery and Apparatuses). Forty percent of its output is sold to consumers while 41% is exported. However, most of the input comes from inside the manufacturing sector. Therefore, the same agriculture sector phenomena are not observed here.

The willingness to cooperate calculated by the simulation program show that among all industries investigated, the Food industry is the one with the lowest level of cooperativeness in the real observation. Even though the simulation program captures the trend on lower level of cooperation, there is an associated error which is positive for this industry. Despite the eventual error on the scale, the findings related to this case are valid and may add a lot of intuition for policy makers.

With this studied case, we foresee two improvements necessary on our model to improve its accuracy. The first one is the correct definition of factors that could capture systematic industry differences. The second is the inclusion of sectors other than manufacturing industries. These would be especially important if one wants to investigate industries with high level of input/output transactions with other sectors. The policy implication we extract from the finding is that clustering policies designed for industries SIC-24 or SIC-25 must include instruments that guarantee the flow of relationship between firms from both sectors. Generally speaking, concentration policy effectiveness is related to the correct interference on the cross-sector vertical integration. In highly integrated sectors which do not depend on other industries, the outcomes of clustering are expected to be higher than on other industries with a higher distribution of supplier/consumer industries.

4.2.2 Incentives policy

There are several ways governments may intervene in order to encourage companies to cooperate. They may financially stimulate companies to cooperate through grants, subvention, and tax exemptions or by subsidizing resources to be used in joint projects. There are also additional types of measures such as: providing platforms for cooperation and experimentation; raising public awareness of technology and benefits for knowledge exchange and networking; acting as a facilitator and moderator of networking; and demand pulling by government procurement. Roelandt and den Hertog

(1999) provide a comprehensive study about what governments have been done towards networking and clustering. In this policy scenario, we are interested in simulating a policy that provides incentive to firms to cooperate more.

This scenario of policy was defined as some sort of government intervention that gives necessary incentives to firms to promote innovation cooperation. We implemented this policy in two different ways: (i) firms from certain industry have their willingness to increased cooperation, i.e. firms from the policy sector start to feel more attraction to other firms, and (ii) firms have an additional incentive to cooperate with firms from the policy sector, i.e. independently of the sector they are. In the first implementation, firms from the policy sector search more for cooperation, while in the second case, they are more searched. These effects are applied in both intra- and inter-sectoral partnerships. We implemented the two different ways in order to test if there would be significant differences in one or other approach. From incentive policies, we expect an increasing numbers of firms cooperating as well networking.

The results are shown in Figure 10 and Figure 11 with different types of view. The results for both implementation strategies show the expected outcome of increasing cooperation of firms in the sector whenever a policy is applied to it. As observed in the first policy strategy scenario, industry SIC-25 again showed to suffer a negative influence from policies applied to industry SIC-24. However, we have found insightful results in terms of cross-sector spillover effects related to industry SIC-31. It is affected by industry SIC-32 in both strategies and by industry SIC-34 in the case of the second strategy scenario.

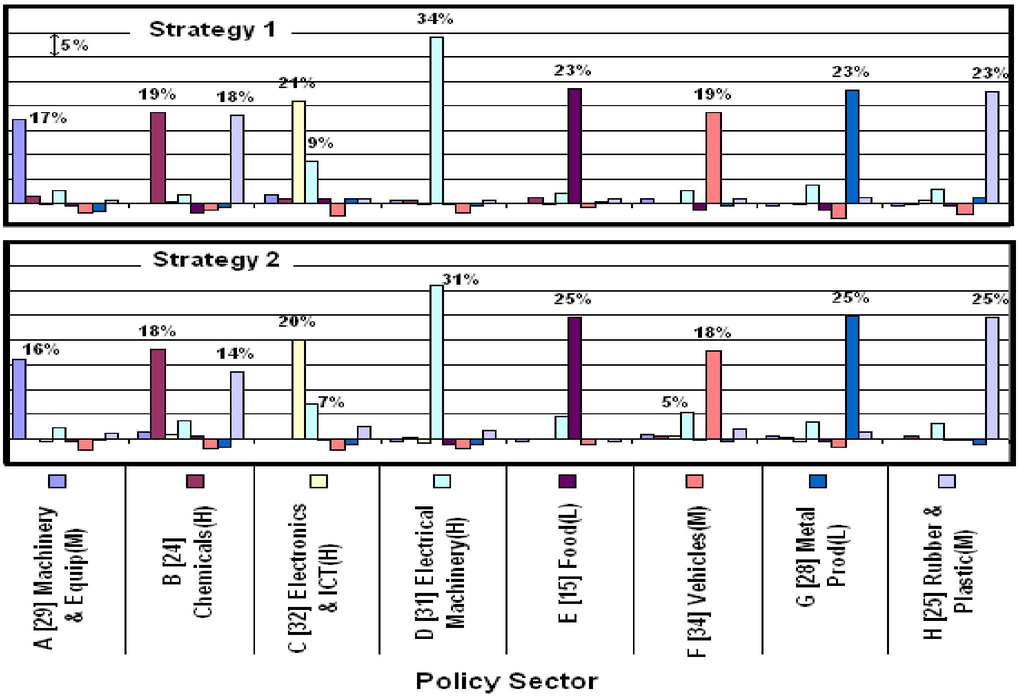

Figure 10. Impact on number of firms cooperating (incentives scenario)

Figure 10 shows the gain on cooperation of the two strategies when compared with the no-policy scenario. Figure 11 shows the number of firms cooperating when the policy with the second strategy is applied, the total number of firms in the sectors and the number of firms cooperating in the real observation.

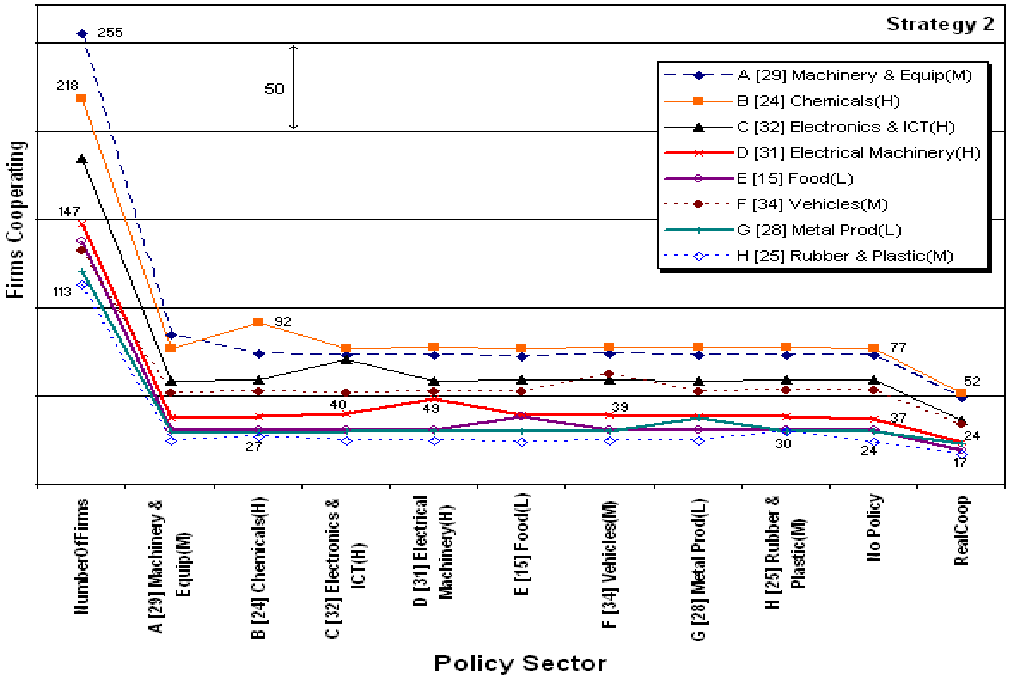

Figure 11. Number of firms cooperating

Result from test comparing outcomes on the two different implementations show that the effects are statistically the same at 5% level of significance for all intra-industry effects. For the spillover effect from industry SIC-24 on industry SIC-25, the gains in cooperation were higher when strategy 1 was applied. The inter-industry effects over industry SIC-31 showed no significant statistical difference among policies applied in Electronics & ICT or Motor Vehicles industries.

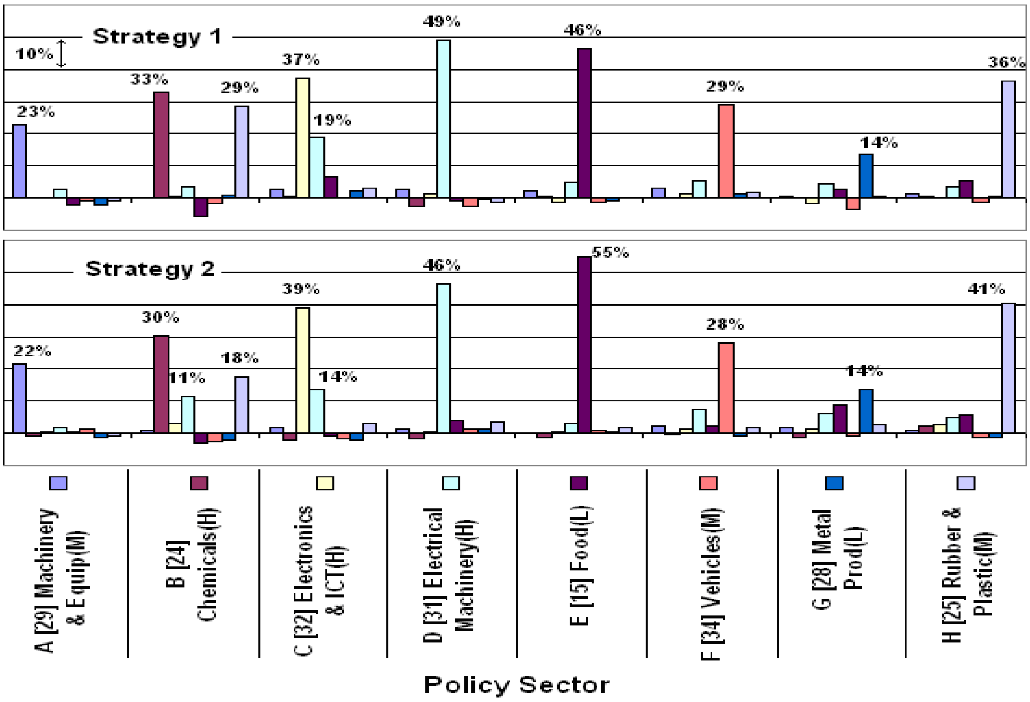

Figure 12. Impact on number of firms networking (incentives scenario)

For the gains in the number of firms networking (Figure 12), the dispersion of the values from the average showed to be very high. The effects on sectors SIC-15 and SIC-32 are statistically the same in both strategies and both industries. As occurred with the gains in the number of firms cooperating, the values were statistically the same in both strategies, when considering intra-sector effect. A new finding, when applying the second strategy for sector SIC-24, was the spillover effect on industry SIC-31, which is statistically different from the same outcome in strategy 1.

As discussed in the last session, the analyses of the outcomes related to industry Rubber & Plastic showed that it is within the Chemicals industry where most of the transactions for this industry occur. Rubber & Plastic suffers a great dependency on Chemicals industry. Naturally, when firms are searching for partners to cooperate in R&D, they will prefer to choose among the ones with larger amount of transactions. For this policy and strategies, the structure of partner industries for firms in Rubber & Plastic was similar to the one presented in Figure 9, except that there is a small increase in partnerships with industries SIC-31, 32 and 34. The number of intra-sectoral partnerships was also stable, independently of the policy sector, and the main source of gains in the number of partnerships for this sector continued to be with industry SIC-24. In Figure 13, the evolution of partnerships among firms in sector SIC-24 and other industries can be observed. Industry SIC-25 also played a major role in cooperation. It is the most important industry when considering inter-sectoral partnerships.

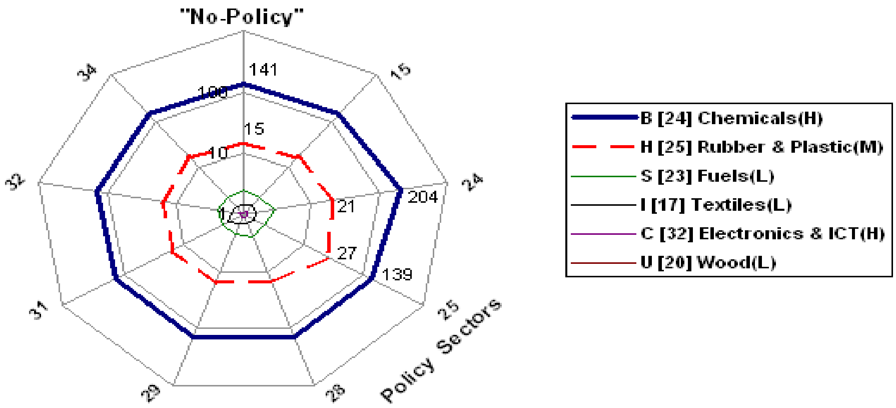

Figure 13. Partner industries for sector SIC-24 (incentives scenario, policy strategy 1)

Industry SIC-31 (Electrical Machinery and Apparatuses) is an interesting case. The structure of partner industries differs from one policy strategy to the other. The usual partnership for firms from this industry is basically intra-industry, with industry SIC-32 and very few cases with industry SIC-25. However, when using the second strategy, few partnerships emerge with firms from sectors SIC-24, 28 and 29. The interesting thing about this outcome is that these sectors have the minimal attractiveness in terms of the transaction table but not enough to make firms from sector SIC-31 to be attracted to them. However, when firms among these three industries becomes more attractive, firms in sector SIC-31 start searching partnership with them.

Electrical Machinery and Apparatuses basically transacts with consumers and foreign customers. Eighty-one percent of its output is destined to either one of these target markets and an additional 4% is destined to customers outside the manufacturing sector. From our set of firms, the customers or competitors would be firms from the same industry. Firms from outside this sector may only be suppliers. Thus, it shows that vertical cooperation may be enhanced with the appropriate policy.

From the two different implementation strategies applied in this policy scenario case, we have observed statistically similar outcomes in terms of gains in the number of firms cooperating. However, we have found that more inter-sectoral cooperation is possible when applying the second policy strategy. We have observed in the industry SIC-31 case the effect goes in the opposite direction of that observed in Food industry when the first policy strategy is applied. There was a huge impact on Food industry not observed on Electrical Equipment industry. However, this industry relies basically on suppliers from inside the manufacturing sector. Comparing this policy with the one discussed in the previous session, there is a completely different outcome in the Rubber & Plastic industry. Instead of negative effect, we observe extremely positive effects when applying policies to Chemicals. The different results are found to be caused by the strong vertical linkage between these two industries. This simulation exercise suggests that incentive policy is more effective to enhance vertical links, while clustering policies are more effective to enhance horizontal links.

4.2.3 Spin-off policy

Our third and last policy scenario tests a government policy that would foster entrepreneurship among Korean R&D personnel through promotion of companies that would spin-off from the existing incumbent companies. Small start-up companies would arise from existing manufacturing firms when a small number of R&D employees decide to be entrepreneurs. A similar scenario was studied before using an agent-based simulation model (Pyka et al., 2007).

Spin-off companies arising on the same market as their mother companies would have a number of advantages when compared with completely new start-up companies. The pre-existent experience from its entrepreneurs is supposed to improve innovative advantage through the knowledge accumulated in their carrier and the pre-existent involvement with competitors, suppliers and customers' network. For good reviews about the spin-off theories and the advantages of this pre-existent knowledge capability, one may refer to Agarwal et al. (2004), Dahl et al. (2003), Helfat and Lieberman (2002), Shane (2000) and Lindholm-Dahlstrand (1997).

In this exercise, we want to understand how different industries behave when the firms with higher innovative and cooperative characteristics are introduced into the market. The simulation game starts exactly like the two other policy scenarios. Then, the policy action takes place and firms from the addressed policy sector start generating spin-off companies. A firm generates a spin-off company if it has at least some minimal number of available R&D employees. The new firm is created with at least two and a maximum of ten R&D employees which are the entrepreneurs coming from the incumbent company. In addition, they hire a proportional number of other types of employees, but limited to a maximum of 3 times the number of R&D employees. That is to give the spin-off company a high level of R&D intensity. The newly founded company has exactly the same characteristics as the incumbent company. However, there is an additional willingness to cooperate, associated with them, in order to observe the effects of the policy in the landscape.

The number of firms originated in the spin-off process, occurred at the beginning of the simulation game, varies considerably from industry to industry, due to the constraints of the model. Motor Vehicles industry had the highest increase in the number of firms (28%), while Rubber & Plastic had the lower increase among the 8 studied industries (11%). According to the constraints of the model, industries may be identified either as favorable or unfavorable to spin-offs. The most favorable ones are SIC-34, 24 and 32; and the most unfavorable ones are SIC-25, 15 and 28.

In Table 3, we present the impact on the industry when the policy is applied to it. We have found an overall increase in the number of firms cooperating and networking for every industry. It is a sufficient condition for the observed gains. Thus, we needed to extract the percentage of new firms added to the landscape from the overall gain in cooperation and networking.

Table 3. Gains from spin-off policy within the sector

				# of Firms Cooperating		Firms Networking	
Policy & Firms Sector	**Firms**	**New Firms**	**Increase (A)**	**Gain (B)**	**Net Gain (B-A)**	**Gain (C)**	**Net Gain (C-A)**
15-Food	137	16	12%	27%	15%	43%	32%
24-Chemicals	218	52	24%	24%	1%	20%	-4%
25-Rubber & Plastic	113	12	11%	33%	23%	44%	34%
28-Metal Prod	120	16	13%	19%	5%	15%	2%
29-Machinery & Equip	255	48	19%	24%	5%	18%	-1%
31-Electrical Machinery	147	24	16%	23%	6%	8%	-8%
32-Electronics & ICT	184	45	24%	26%	1%	19%	-5%
34-Vehicles	132	37	28%	21%	-7%	14%	-14%

The first interesting finding is that for industry SIC-34, there is a net loss in the numbers of firms cooperating and firms networking. It means that the gain in the number of firms cooperating is smaller than the increase in the number of firms. For the other two industries which are highly favorable to spin-offs (SIC-24 and 32), the gains in number of firms networking was equivalent to the increase in the number of firms, but the net number of firms networking suffered a loss when the policy was applied to these sectors.

For the industries unfavorable for spin-off (SIC-15, 25 and 28), we obtained completely different results. There was a large net gain for industry SIC-25 in both cooperating and networking firms, while the gains were less significant for industry SIC-28. For significant gains in inter-sectoral effects, we have found the same outcomes of the previous policy scenarios. Industry SIC-25 was strongly influenced by industry SIC-24, what is in line with the results obtained from the first two policies. We have also found an inter-sectoral spillover effect from industry SIC-32 on industry SIC-31, what is in line with both strategies in the incentives policy scenario, but we have not found any significant effect in industry SIC-31 coming from industry SIC-34.

For the three industries with lower level of spin-offs, the differences in gains are resulted from the different kinds of partnership the firms in these sectors have. Industry SIC-15 result relied on intra-sectoral partnerships with firms within the same sector. The increase on the number of firms in the landscape would have a concentration effect that would naturally cause the increase in the frequency of cooperation. This effect was previously observed in analysis of clustering policy. For industry SIC-25 – in which firms rely more on partnerships with firms from industry SIC-24 than on intra-sectoral partnerships – an increase in the number of firms in any of the two sectors (24 and 25) caused gain in the number of firms cooperating.

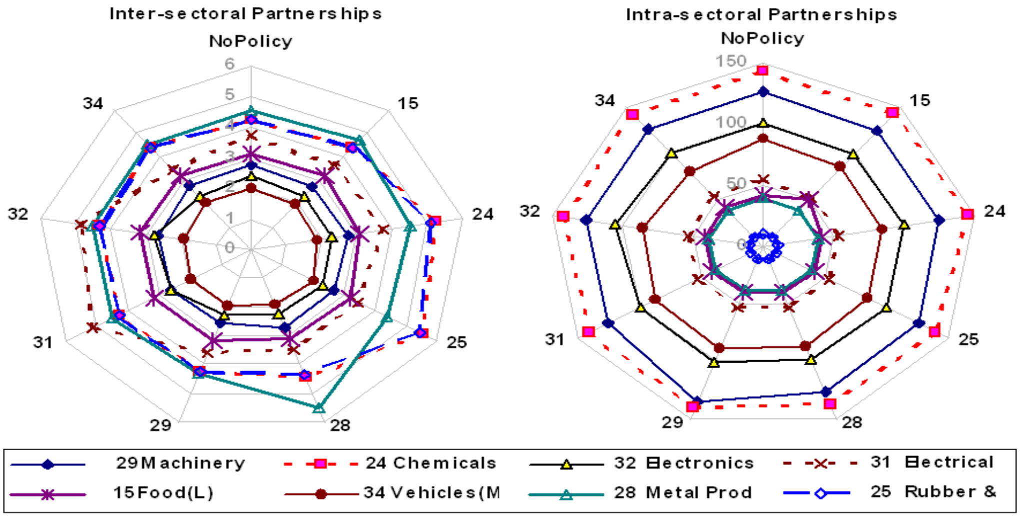

Figure 14. Effects of policy in inter- and intra-sector partnerships (spin-off scenario)

Figure 14 shows that, in the Motor Vehicles sector (SIC-34), there was a negative effect on intra-sectoral partnerships, while partnerships with other sectors remained stable and independent of the sector subjected to policy change. For industries SIC-32 and SIC-24, intra-sectoral partnerships remained stable, while inter-sectoral partnerships increased in magnitude with SIC-31 and SIC-25. Whenever a policy was applied in industry SIC-24 or SIC-25, the number of partnerships increased between the two sectors. The same happened between SIC-32 and SIC-31. However, the amount of the increase from inter-sectoral partnerships was not significantly different in relation to the total amount.

The findings suggest that the strong reliance on inter-sectoral partnership in Food sector is responsible for its strong gains. The decrease in intra-sectoral partnerships in industry SIC-34, suggests that an increase in the number of firms would spread partnerships on the landscape and decrease the formation of strong networks. Lower number of partnerships for higher number of firms cooperating means smaller size of networks and even lower number of networks. There is trade-off between number of networks and number of participants in a network and the gains to firms from cooperative enhancing policy measures.

A spin-off policy showed to always increase the absolute number of firms cooperating, however, relatively to the number of newly created firms, the effect may be even negative. The policy may work better when inter-sector links are very strong, as well as to horizontal links. The policy also showed that it may affect negatively the concentration of firms networking, even though it may increase the number of firms cooperating – some sort of scattering effect. A spin-off policy in Korea would be specially challenging, since the market is highly dominated by big incumbent enterprises. Having instruments for checking the effectiveness of such policies is very important. This simulation exercise is just an example of how an agent-based simulation may help policy makers in their decision concerning network and cooperative policy measures.

5. Final Remarks

Clusters and network policies, on national and regional level, have been conducted by a number of governments worldwide in both industrialized and developing countries in order to increase economic development and industry competitiveness. Micro-level studies of R&D cooperation among firms and other types of organizations has received great emphasis from policy makers as it facilitates knowledge transmission, reduced R&D cost, increased innovative capacity and generates useful information for targeted public interventions.

The aim of this research was to develop an agent-based simulation model that could be used to show how this technique may be useful in the design of policy tools toward cooperation in innovation activities. Then, we have introduced an agent-based model representing the dynamic processes of cooperative R&D in the manufacturing sector of South Korea. The main dataset utilized in the simulation game came from the Korean Innovation Survey 2005 covering innovation activities from 2002 to 2004 developed by firms with at least 10 employees. The work was divided into four phases.

In the first phase, we have surveyed previous studies about the determinants of firms' behavior when conducting R&D activities. We also have surveyed existing studies conducting agent-based simulation games about firm's cooperation in innovation. From this step, we extracted the theoretical background to be applied in the following steps.

In the second phase, we have conducted regression analysis using the target data to identify the significant determinants of cooperation in R&D in South Korea. A multivariate probit regression model was defined as a system of four different binary choice equations to identify firms' characteristics and defining their likelihood to cooperate with customers, suppliers, competitors and research institutions. The results from this analysis allowed us to define a more accurate view of firm's rationale regarding to their choice whether to cooperate or not and with which kind of partners.

In the third phase, we have defined our simulation model of manufacturing firms' cooperation in innovation. The agents are heterogeneous in their characteristics and behaviors. The attraction forces and probabilities to establish cooperative links with other firms were defined by a set of determinants and rules extracted from theoretical assumptions and empirical evidences. The simulation model was then validated by finding, in the artificial world when compared to the real world. The model accomplished partnerships between firms, including inter-sectoral alliances.

After reaching an accurate calibration on the simulation model, in the last phase accounted for testing three different policy scenarios: clustering, incentives and spin-offs. These policy drives were applied to each one of the eight larger industries and the outcomes compared with a no-policy benchmark scenario to verify the gains (or loses) in the number of firms cooperating and networking, and size and number of networks.

The analysis shows that firms' decision to cooperate with partners is primarily affected positively by firm's size and the share of employees involved in R&D activities. Then, for each kind of cooperation, there is a different set of particular determinants which either affect positively or negatively the partnership. From the agent-based model we have identified two main contributions to field. The first one is methodological, in regard to the model definition approach and validation procedure. The second one is a new way of defining firm's interaction, namely the use of a gravitational model.

ACE scientists have been using real data on the tasks of finding agents' behavior, loading the initial state of the simulation with real agents, calibrating the system according to observed factors, and verifying that the artificially generated data matches patterns in the observed data. However, we did not find any research in the literature that used all four strategies. The most common approach is to run the simulation with imaginary data and observe in the generated world, stylized facts and regularities of the real world. Another common method is to load the initial state of the simulation with real observed data but play a simulation game where the results are not comparable with any existing pattern in the real world. We believe that this research is a good example on how to utilize empirical and preferably stratified data on all four strategies defined above.

For the gravitational field used in our simulation model, we introduced an alternative way of how to model firm's distribution, movement and interaction in the simulation game within and between industries. Existing studies have been using neighboring relationship on grid landscape, small world interaction, geographical proximity or fully random interaction. We introduced a new way of modeling agents on a landscape which may be an alternative for scholars who deal with some sort of attraction between agents.

From the computational point of view, we also believe that we have made a significant contribution to ACE field. What we have observed from previous studies is that agent-based simulation models are usually visual tools where the user observe the interactions at each step. However, in terms of generating significant and trustable results, a visual and manually operated environment is not the most appropriate one. That is the main reason why we abandoned the using existing visual frameworks and we opted for an implementation in a grid topology – where the simulation is run without human intervention. The simulation grid increased the computational power and allowed us to test much more scenarios than it is usually found in ACE implementations.

The encouraging results, when running policy games, showed that AB models have a great potential to be used in decision support systems for policy makers. We have just applied few examples and showed how the results may be interpreted with this newly developed model. However, its better development and the inclusion of new entities such as research institutions and government organizations would lead to better accuracy and consequent trust on the generated results. The model can be generalized to include a number of extensions but not necessarily limited to those listed below. These extensions can serve as an optimal direction for future research in this area.

An aggregation of existing network information in the calibration process would be of great value for the development of the model. Obviously, the first natural extension of the system is the inclusion of more what if research questions and policy scenarios tested. Another extension tested in this implemented simulation model would be to consider the regional level as the unit of aggregation. With this improvement, one could make the same type of industry level policy analysis but at a regional level. The national, industry or regional levels can also be extended to analysis of determinants of cooperation between national and multinational corporations to enhance skill, management and technology transfer. An additional analysis would be the verification of intermediate states of the networks while they were created. The dynamics and order of partnership creation and how the networks merge with each other would be a great source of insights that one could use to propose policy implications.

We would also suggest improvements in the Korean Innovation Surveys to better capture network formation and cooperative behavior of firms. Questionnaires could be extended to accomplish information such as region and industry classification of partner organizations, number of projects and researchers involved in collaborative R&D, and direct reasons leading companies to decide for their engagements in joint projects. One other interesting use of the current system would be to test it in different countries with similar innovation and network survey data, such as European Community or at the OECD level.

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