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Abstract: This study utilizes results from an agent-based simulation model to conduct public policy simulation of firms' networking and cooperation in innovation. The simulation game investigates 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 public policy strategies include clustering to develop certain industries, incentives to encourage cooperative R&D and spin-off policies to foster entrepreneurship among R&D personnel. These policies are compared with the no-policy alternative evolving from the initial state serving as a benchmark to verify the gains (or loses) in the number of firms cooperating and networking. Firms' behavior is defined according to empirical findings from analysis of determinants of firms' participation in cooperation in innovation with other organizations using the Korean Innovation Survey. The analysis based on manufacturing sector data 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, each cooperative partnership is affected by a different set of determinants. The agent-based models are found to have a great potential to be used in decision support systems for policy makers. The findings indicate possible appropriate policy strategies to be applied depending on the target industries. We have applied few examples and showed how the results may be interpreted. Guidelines are provided on how to generalize the model to include a number of extensions that can serve as an optimal direction for future research in this area.

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

JEL Code: C15; C71; D21; D85; L20; O31;

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1. Introduction

Changes in technology and globalization of economy has led to increased interest in research on firms' networking and cooperation in R&D. This is reflected in the increased number of studies on innovation networks and cooperation activities appearing in the evolutionary economics and innovation literatures. However, few empirical works have been conducted toward modeling the processes by which these networks of cooperative R&D are formed and their outcomes. The complexity of the dynamics processes involved and the heterogeneity of the agents (firms) has made it difficult to model related problems using traditional techniques. As a result, in recent years, a new technique, Agent-based Computational Economics (ACE) has been developed to conduct Agent-based (AB) simulation with the objective to model the processes of networks, innovation activities and technological change.

The new technique, ACE, tries to study the economy as an evolving system of autonomous interacting agents. It enables social scientists to conduct "laboratory experiments" aimed to observe the effects of specific changes and policies on the agents' performance and economic outcomes (Tesfatsion, 2001). AB simulation has been used among others on models which allowed to have insights about firms' innovation network and cooperation activities. Examples include: 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; Gilbert et al., 2001), trust relations among partners (Daskalakis and Kauffeld-Monz, 2007), etc.

In recent years, many empirical studies have been conducted based on standardized Innovation Survey Databases. These studies aim to capture impact of agents' rationale on the conduction of cooperative R&D (Dachs et al., 2008; 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. Katz et al., 1990). In this research, we are making use of AB simulation to model cooperative R&D among firms of the manufacturing sector in Korea. Modeling of firms' cooperative behavior is based on their observable characteristics (Eum et al., 2005). The agent-based model represent the dynamic processes of cooperative R&D. The main dataset came from the Korean Innovation Survey 2005 covering manufacturing 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 surveyed previous studies about the determinants of firms' behavior when conducting R&D activities and studies conducting AB simulation games about firm's cooperation in innovation. From this step, the theoretical background applied in the following steps was extracted. In the second phase, multinomial probit regression analysis was conducted to identify the significant determinants of cooperation in R&D in South Korea. The model was defined to identify firms' characteristics and defining their likelihood to cooperate with customers, suppliers, competitors and research institutions. The first 2 phases are presented in Lenz-Cesar and Heshmati (2012). In the third phase, the simulation model of manufacturing firms' cooperation in innovation was defined. 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. The phase three is presented in Heshmati and Lenz-Cesar (2013).

From the definitions of firms behaviors presented in Heshmati and Lenz-Cesar (2013) in this research we have implemented the model as social gravitational landscape where firms attract each other based on their individual characteristics, such as size; their rationale when conducting or avoiding innovation activities; and the industry they belong to. This attraction would eventually result in firm's interaction which could generate R&D partnership. R&D cooperation 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. In the last phase we accounted for testing three different policy scenarios: clustering, incentives and spin-offs. The information that these policy scenarios are built on is generated in the third phase. The amount of work involved and space limitations implied to conduct the two phases separately. These policy drives were applied to each one of the eight larger industries and the outcomes compared with a no-policy scenario to verify the gains (or loses) in the number of firms cooperating and networking. 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.

The validation of our approach is done by running the model from an empty basic condition (no cooperation) till reaching a convergence to the quantitative real state of firms in 2004. 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 and observed the quantitative outcomes. 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 test proposed policy strategies. 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 policy; and so on. In sum, the designed policies are industry specific allowing for heterogeneity in impacts.

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 to identify the cooperation determinants and to specify the cooperation relationships of firms. The simulation model is described in Section 4 and the various policy scenarios and results are discussed. In Section 5 we make a brief review of the outcomes from this research and suggest extensions that can serve as an optimal direction for future research.

2. Literature

In regards to cooperative innovation, Schumpeter (1934) 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; 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.

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, and non-profit organizations. 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. Freeman (1987) shows that competitiveness is becoming more and more dependent on external acquisition of complementary knowledge. Besides, inter-firm networking and cooperation's importance are emphasized by the increasing complexity, costs and risks involved in the innovation process.

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) and on welfare (D'Aspremont and Jacquemin, 1988); the positive impact on innovation performance and knowledge spillover (Miotti and Sachwald, 2003); and that intra- or inter-firm cooperative competency is a key factor affecting success in 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 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 consider ways to maximize productive cooperation among domestic R&D firms. Firms may cooperate vertically or horizontally. Cooperation in general is shown as beneficial to firms' performance in a general way, by increasing innovation output and maximizing economic growth in national level.

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 especially in knowledge sharing and product/process development (Child et al., 2005; Sakakibara, 2001; Bayona et al., 2001). The main reason that drives any firm's decision is, the profitability of its business. Lenz-Cesar 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 Spanish manufacturing firms that have carried out R&D activities. The main findings of this study include: firms perceiving risk constraints; large firms; to achieve better product quality; and firms in higher technology intensive sectors tend to cooperate more than others.

Other interesting outcomes regarding to propensity to cooperate may be found in Belderbos et al. (2004a) using data from Dutch Community Innovation Surveys. Dachs et al. (2008) studied innovation cooperative behavior analyzing data from Finland and Austria. The rate of cooperative firms in Finland is considerably higher than in Austria. Mark and Graversen (2004) analyzed Danish data containing 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.

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, firms in R&D-intensive industries cooperate in order to enter other R&D-intensive industries.

Innovation Networks

The definitions and varieties of networks in innovation are broad. Excellent conceptual studies about networks are found in Powell and Grodal (2004). National Systems of Innovation, originally defined by Freeman (1987) have been widely adopted as a theoretical framework for policy making. 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 to their innovative capacity. There are also other benefits that networks may offer, such as economies of scale, economies of scope, and risk sharing (Boekholt and Thuriaux, 1999). Even though the benefits of networks and clusters are clear, there are also a number of barriers for the formation of networks (Forfás, 2004). Governments must be aware of the barriers and play a major role on fostering and creating conditions for network formation. Boekholt and Thuriaux (1999) point out a set of roles from public policy to counter the “system deficiencies” that hamper the formation of 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 the:

Italian Industrial Districts (Pyke et al., 1990) – Organized government co-operatives made possible that small companies could compete effectively with large and well established enterprises worldwide.

Danish Networks Programme (Pyke, 1994) – Government funds supported networks of companies co-operating. 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. 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 some universities and companies in the mobile phone industry.

Japanese Engineering Research Associations (Sigurdson, 1998) – were institutional arrangements to promote collaborative R&D between companies. A successful case is the Camera Association (Sakakibara, 2001).

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 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 (ABS) in Innovation Networks

ACE is composed by elements from computer science, economics and the social sciences. These elements are combined in a simulation system to study artificial societies. As pointed by Pyka and Fagiolo (2005), the current computational power has led to massive use of numerical approaches. ACE, an acronym used by Tesfatsion (2001), tries to study the economy as an evolving system of autonomous interacting agents. 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. Economy is suggested to be a complex system which is difficult to explain with standard models (Kirman, 2004). According to Axtell (1999), simulations should be performed in parallel to traditional mathematical models or even as substitute. The main ingredients of ACE models are explained in Tesfatsion (2001), Fagiolo et al. (2007) and Richiardi (2007).

Dawid (2005) surveys a considerable set of works related to simulation and innovation, starting with a study about the interplay of industry evolution. The capability of agent-based models to capture dynamics and complexity is exactly what is needed to study firms’ cooperation and innovation networks formation (Morone and Taylor, 2012). The studies described below were made to investigate interactions between firms when conducting innovation activities.

Beckenbach et al. (2007) investigated the behavioral foundation of agents 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. Daskalakis and Kauffeld-Monz (2007) also 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 and proved the relevance of trust and trust building mechanisms.

Three authors who are very active in innovation networks research area have long been working together investigating innovation networks with agent-based models (Gilbert et al., 2001; Ahrweiler et al., 2004; and Pyka et al., 2007). Gilbert et al. (2001) implemented their model for two real cases of networks: Mobile and Biotech, both described in Pyka and Küppers (2002). The outcomes were considered qualitatively satisfactory by the authors. Pyka et al. (2007) included some firm dynamics in the model which allowed the creation of new start-up firms based on successful ones.

Pyka and Saviotti (2000) developed a model to investigate innovation networks in the biotechnology sector. The model attempted to represent the roles of large diversified and dedicated firms on network formation. Albino et al. (2006) also developed an agent-based model to simulate the process of innovation in an industrial district. Four different scenarios were tested. Morone and Taylor (2012) deal with proximity for partnership formation in the province of Foggia in Italy. They conducted a focus group, in order to capture network formation, agents rationally and benefits.

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. ABS of cooperative innovation in R&D used in this study is explained in Heshmati and Lenz-Cesar (2013). For further readings about methodological issues one should refer to Pyka and Fagiolo (2005).

4. Policy Scenarios

Here we will discuss about the extension of our simulation model to accomplish future scenario analyses. 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 50 time periods or steps. The simulation is run with the objective of observing the outcomes in terms of additional number of cooperative firms. This is done at first with no policy intervention serving as a reference scenario to be compared with the policy scenarios. Next it is run the same number of steps but with some policy intervention.

We considered aggregated data on industry SIC 2-digit level. 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. 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. An average percentage of 19% of the firms are left without any cooperation due to incompatibility to the existing available potential partners.

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. 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.

Figure 1 is a snapshot of the result of the simulation game in a no-policy scenario evolving from the initial state. The numerical results for the no-policy scenario compared with the results found in the final calibration set can be visualized in Table 1 and Figure 2. Table 1 presents the result for the industries with more than 100 firms, which will be the focus of our analysis.

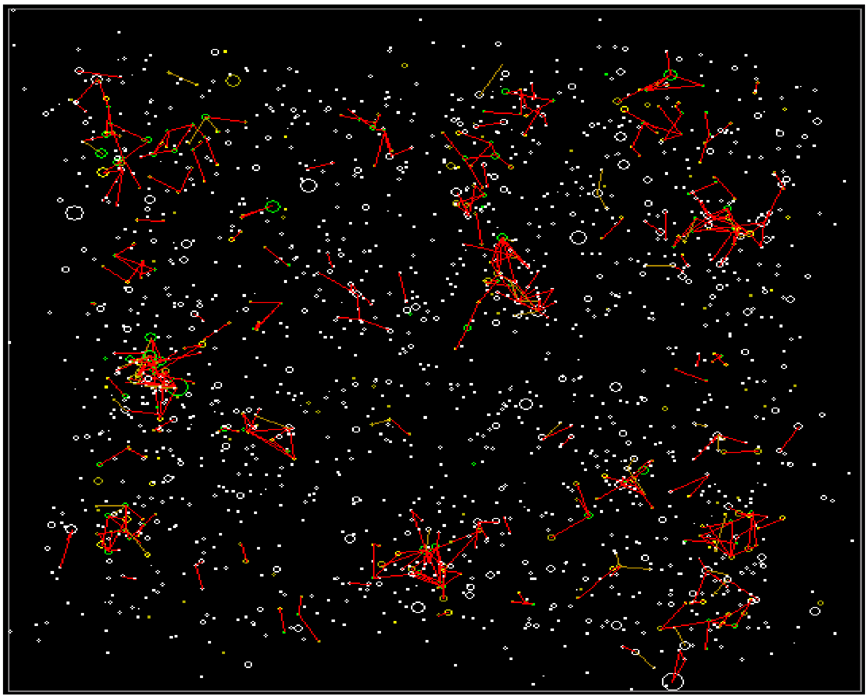

Figure 1. Final landscape with no policy intervention

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%). 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, for impact of the no-policy scenario on the number of firms cooperating, the means of Electrical Machinery and Vehicle industries have statistically the same cooperation rates. Another interesting observation reported on Table 1 is that firms in Food and Electronics and ICT Equipment industries appeared with greater cooperative potential. Metal Products presented the lowest cooperative potential.

As it becomes evident in the Figure 2, the number of firms cooperating sometimes is really low even for the chosen +100 firms industries (17 firms for Rubber & Plastic). Adding or dropping one firm may cause variations over 5% interval. This is the reason why we have selected only the set of the 8 larger industries to be part of our analysis.

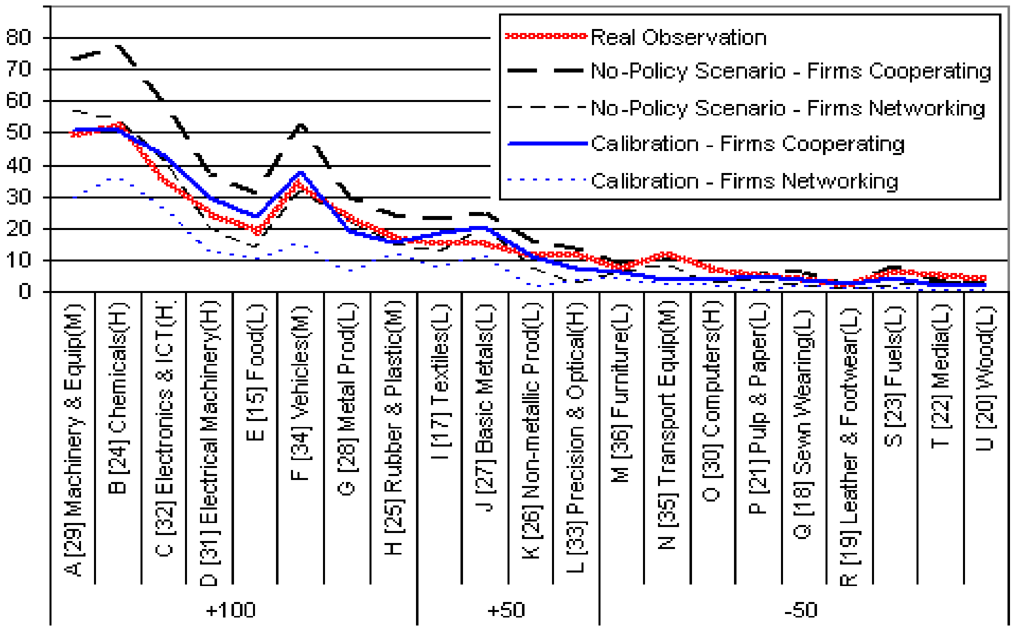

Figure 2. Number of firms cooperating and networking

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 or the no-policy scenario presented (Figure 3). Next we introduce the policy instrument, and run the simulation for some 50 steps. In this research, we implement 3 different policies using 4 different abstractions. Each policy instrument is run for a specific industry, among the 8 larger industries. The objective is to observe how different policies may produce different outcomes across industries. Attempt is made to attribute the differences to observable characteristics of the industry.

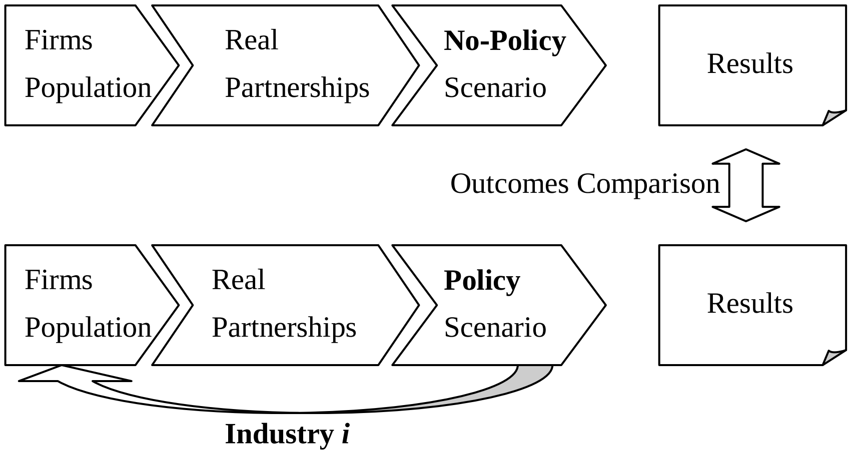

Figure 3. Policy scenario simulation

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).

Korea is well known by the conception and implementation of industrial complexes policies taken place throughout the country. 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. Korea 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 of the S&T system and business activities (Lee, 2001).

In the KIS-2005 database, 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).

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 4 displays clustering policy being applied to Electronics & ICT industry on the left upper side of the landscape.

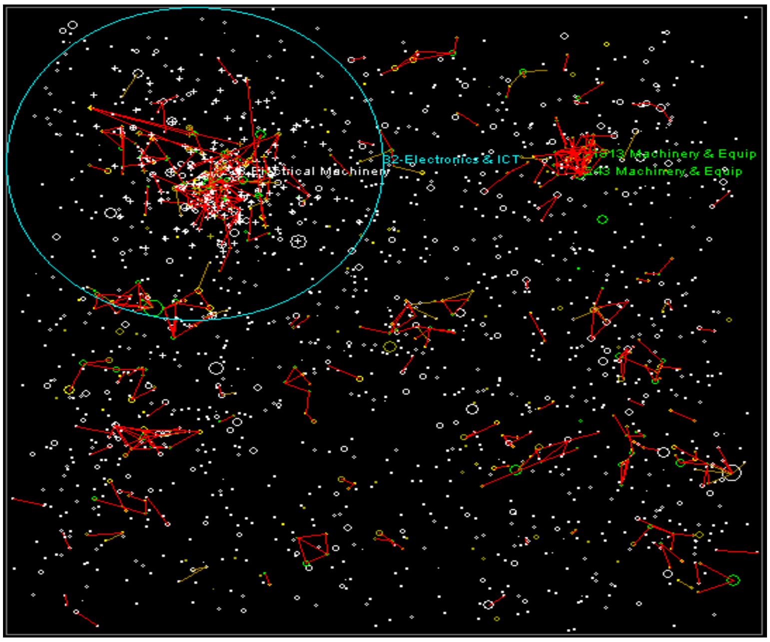

Figure 4. Clustering policy scenario 1 for industry SIC-32

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 5), we find that this is true for every industry, except Rubber & Plastic industry in which the policy has a negative effect on the number of firms cooperating. The Food industry is found to be the one with greater impact. There is sufficient evidence that this policy when applied to Electrical Machinery industry would produce lower impact than when it is applied to Electronics & ICT. The Rubber & Plastic industry suffers a negative impact when the policy is applied to Chemicals industry. This shows evidence of a cross-sector effect.

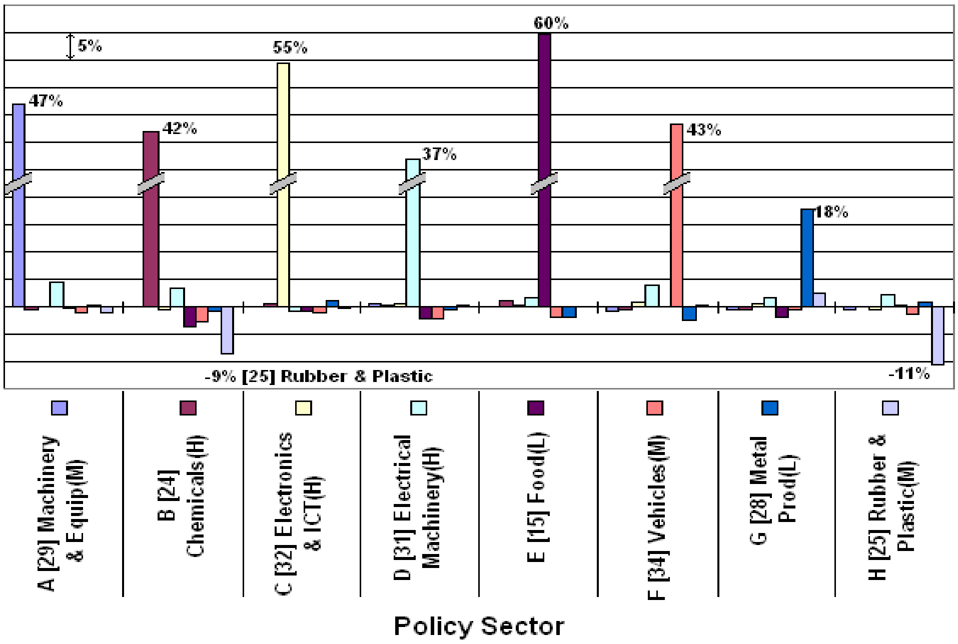

Figure 5. Impact on the number of cooperating firms (clustering scenario)

In Figure 6 we present the effect of the clustering 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 Electrical Machinery, which originates from application of the policy on Vehicles industry. There is no statistically significant difference between Electrical Machinery and Electronics & ICT industries; and also between Electronics & ICT and Vehicles.

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. Figure 7 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.

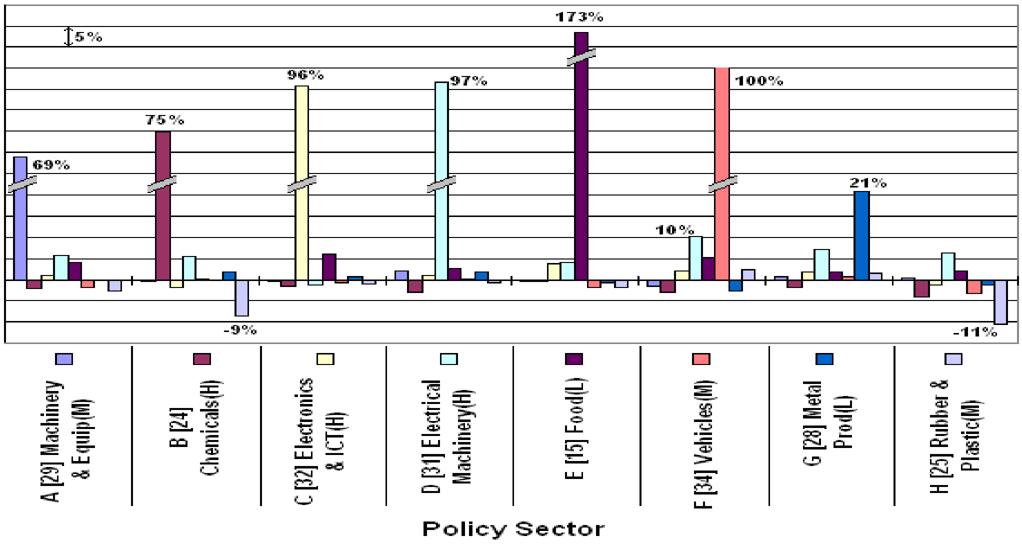

Figure 6. Impact on the number of firms networking (clustering scenario)

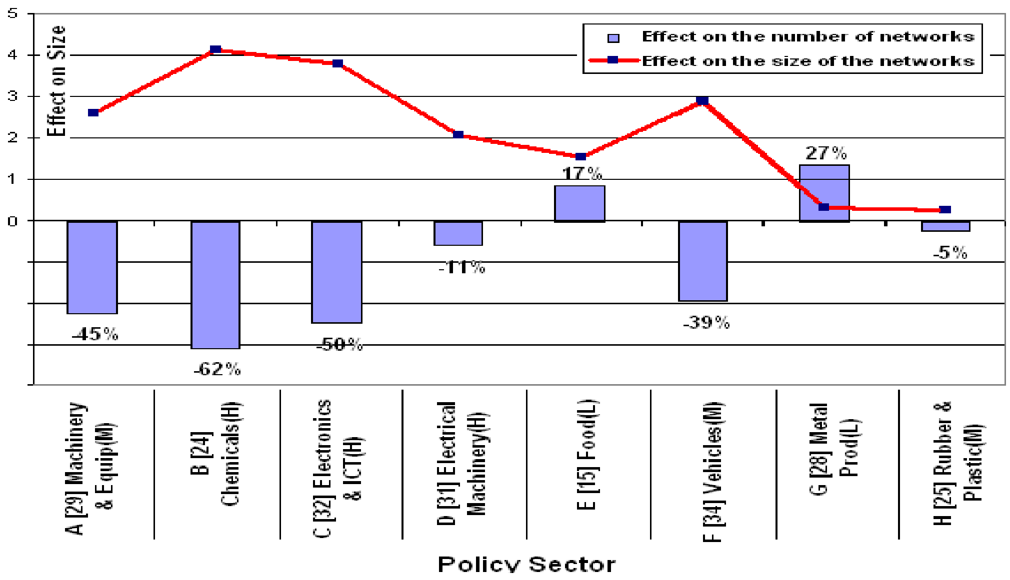

Figure 7. Impact on the size and number of networks on the policy sector

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. Figure 8 shows the number of partnerships between firms from Rubber & Plastic industry and other industries. Except for the line representing Rubber & Plastic industry, 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 Rubber & Plastic industry.

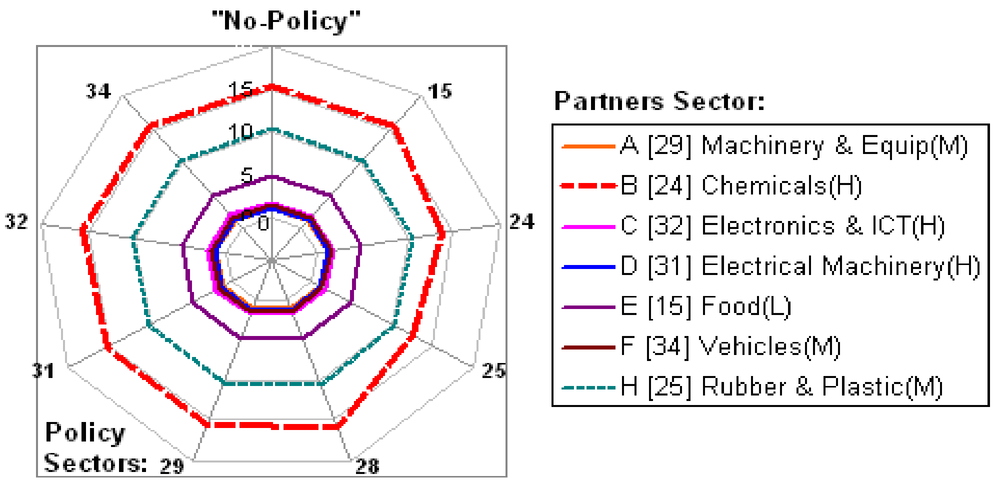

Figure 8. Partners industries relating to industry 25

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. Moreover, firms on Chemicals industry have more willingness to cooperate than firms in Rubber & Plastic.

Figure 8 shows that when the clustering policy is run for Chemicals and Rubber & Plastic industries, 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, 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 Rubber & Plastic industry, we found that firms cooperate more with suppliers than with customers or competitors.

In regard to the large policy effect on Food industry, we found this industry to be not integrated with any other industry. Fifty-one percent of Food industry 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 Electrical Machinery industry. Forty percent of its output is sold to consumers while 41% is exported.

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.

This policy scenario was defined as 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 feel more attraction to other firms, and (ii) firms have an additional incentive to cooperate with firms other than 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.

The results are shown in Figure 9 and Figure 10. The results for both implementation strategies show the expected outcome of increasing cooperation of firms in the sector. As observed in the first policy strategy scenario, Rubber & Plastic industry again showed to suffer a negative influence from policies applied to Chemicals industry. However, we have found insightful results in terms of cross-sector spillover effects related to Electrical Machinery industry. It is affected by Electronics & ICT industry in both strategies and by Vehicles industry in the case of the second strategy scenario.

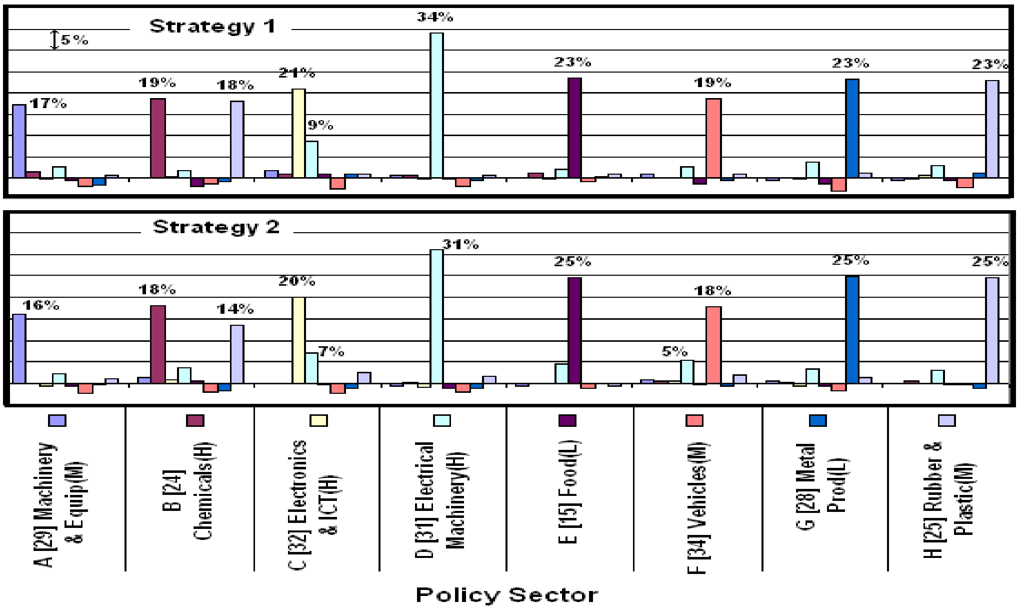

Figure 9. Impact on number of firms cooperating (incentives scenario)

Figure 9 shows the gain on cooperation of the two policy scenario strategies when compared with the no-policy scenario. Figure 10 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 in real cooperating.

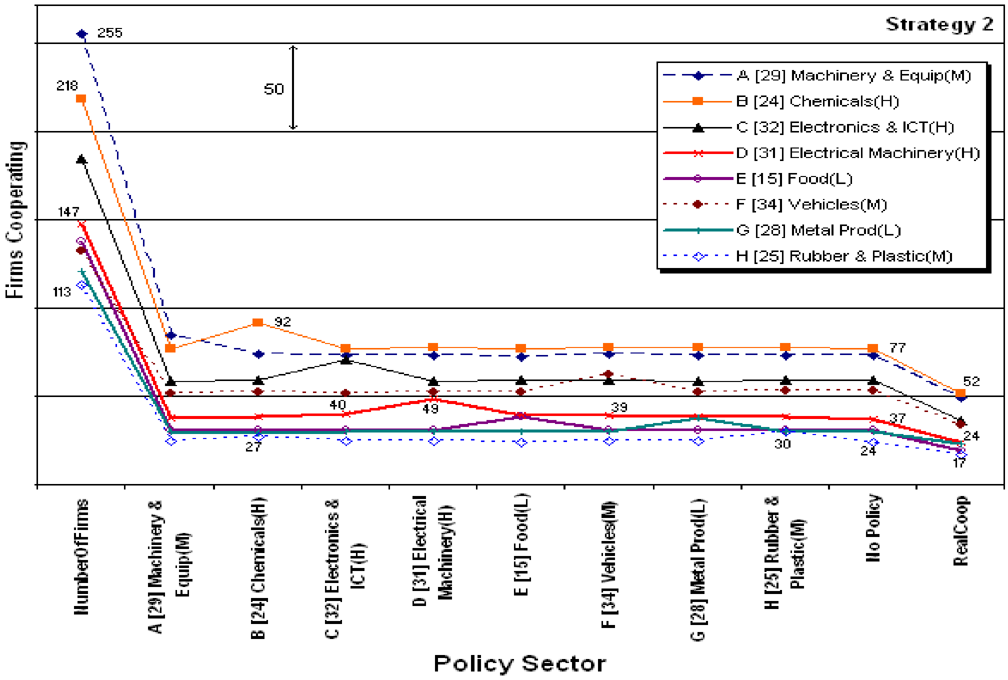

Figure 10. Number of firms cooperating

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 Chemicals industry on Rubber & Plastic industry, the gains in cooperation were higher when the first strategy was applied. The inter-industry effects over Electrical Machinery industry showed no significant statistical difference among policies applied in Electronics & ICT or Motor Vehicles industries.

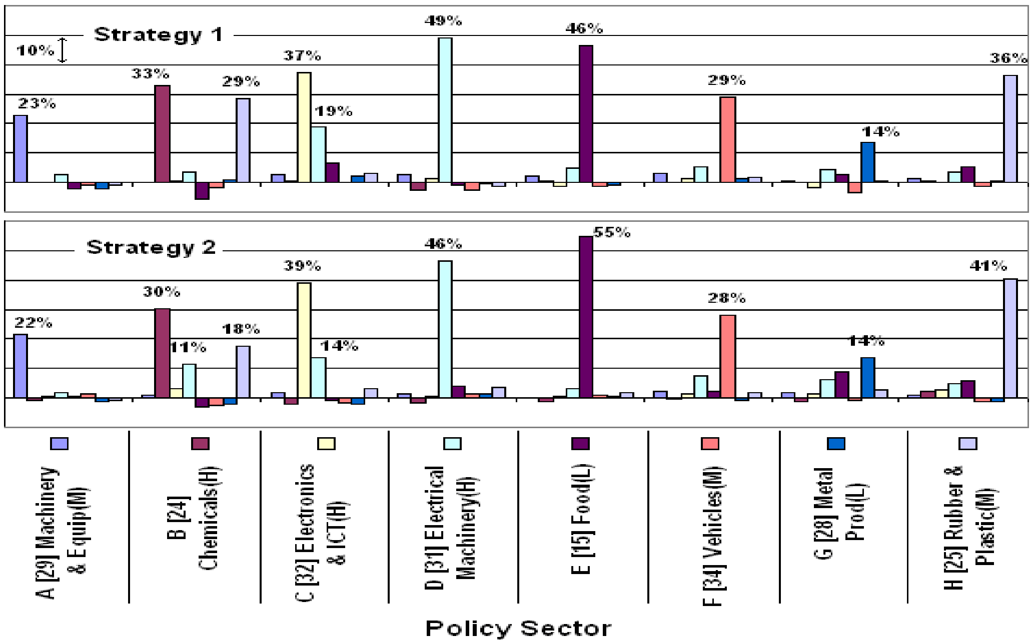

Figure 11. Impact on number of firms networking (incentives scenario)

For the gains in the number of firms networking (Figure 11), the dispersion of the values from the average showed to be very high. The effects on Food and Electronics & ICT sectors are statistically the same in both strategies and both industries. The gains in the number of firms cooperating were statistically the same in both strategies, when considering intra-sector effect. A new finding, when applying the second strategy for Chemicals sector, was the spillover effect on Electrical Machinery industry, which is statistically different from the outcome in the first strategy.

The analyses of the outcomes related to Rubber & Plastic industry 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 8, except that there is a small increase in partnerships with Electrical Machinery, Electronics & ICT and Vehicles industries. 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 Chemicals industry. In Figure 12, the evolution of partnerships among firms in Chemicals sector and other industries can be observed. Rubber & Plastic industry also played a major role in cooperation. It is the most important industry when considering inter-sectoral partnerships.

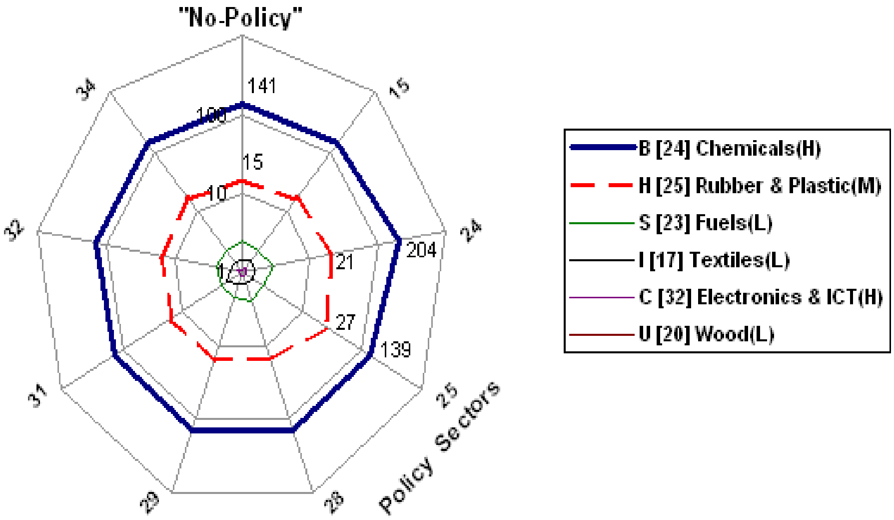

Figure 12. Partner industries for Chemicals sector (incentives scenario, strategy 1)

The structure of partner industries differs from one policy strategy to the other. Electrical Machinery industry is an interesting case. The usual partnership for firms from this industry is basically intra-industry, with Electronics & ICT industry and very few cases with Rubber & Plastic industry. However, when using the second strategy, few partnerships emerge with firms from Chemicals, Metal Production and Machinery & Equipment sectors. From our set of firms, the customers or competitors would be firms from the same industry. 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 Electrical Machinery industry case the effect goes in the opposite direction of that observed in Food industry when the first policy strategy is applied. Comparing incentive and clustering policies, 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. 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 policy scenario tests a government policy that would foster entrepreneurship among 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 R&D employees decide to be entrepreneurs. 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 is supposed to improve innovative advantage through the knowledge accumulated in their carrier and involvement with competitors, suppliers and customers' network (see Agarwal et al., 2004).

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 R&D employees. The new firm is created with at least two and a maximum of ten R&D employees coming from the incumbent company. In addition, they hire a proportional number of other types of employees.

The number of firms originated in the spin-off process, occurred at the beginning of the simulation game, varies considerably from industry to industry. Motor Vehicles industry had the highest increase in the number of firms (28%), while Rubber & Plastic had the lower increase (11%). Industries may be identified either as favorable or unfavorable to spin-offs. The most favorable ones are Vehicles, Chemicals and Electronics & ICT; and the least favorable ones are Rubber & Plastic, Food and Metal Production.

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 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

Policy & Firms Sector	Firms	New Firms	Increase (A)	# of Firms Cooperating Gain (B)	# of Firms Cooperating Net Gain (B-A)	Firms Networking Gain (C)	Firms Networking 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 Vehicles industry, there is a net loss in the numbers of firms cooperating and 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 (Chemicals and Electronics & ICT), 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.

For the industries not favorable for spin-off (Rubber & Plastic, Food and Metal Production), we obtained completely different results. There was a large net gain for Rubber & Plastic industry in both cooperating and networking firms, while the gains were less significant for Metal Production industry. For significant gains in inter-sectoral effects, we have found the same outcomes of the previous policy scenarios. Rubber & Plastic industry was strongly influenced by Chemicals industry. We have also found an inter-sectoral spillover effect from Electronics & ICT industry on Electrical Machinery industry, but we have not found any significant effect in Electrical Machinery industry coming from Vehicles industry. 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. Food industry result relied on intra-sectoral partnerships with firms within the same sector.

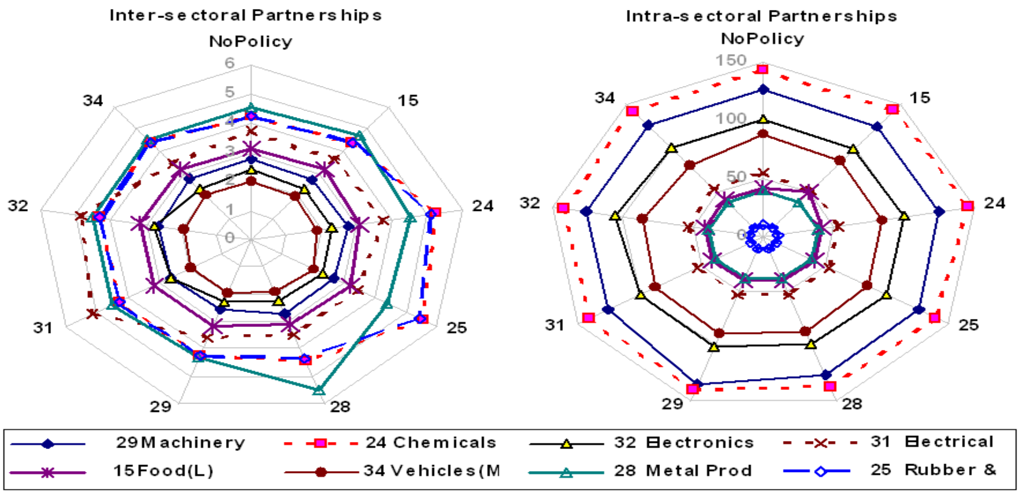

Figure 13. Effects of policy in inter- and intra-sector partnerships (spin-off scenario)

Figure 13 shows that, in the Motor Vehicles sector, 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 Electronics & ICT and Chemicals industries, intra-sectoral partnerships remained stable, while inter-sectoral partnerships increased in magnitude with Electrical Machinery and Rubber & Plastic. Whenever a policy was applied in Chemicals or Rubber & Plastic industry, the number of partnerships increased between the two sectors.

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 Vehicles industry, suggests that an increase in the number of firms would spread partnerships on the landscape and decrease the formation of strong 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. The policy showed to always increase the absolute number of firms cooperating. The policy may work better when inter-sector links are very strong, as well as to horizontal links. A spin-off policy in Korea would be specially challenging, since the market is highly dominated by large incumbent enterprises.

5. Final Remarks

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 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. The first three phases are presented in Lenz-Cesar and Heshmati (2012) and Heshmati and Lenz-Cesar (2013).

In the first phase, we surveyed previous studies to extract the theoretical background applied in the following steps. In the second phase, multinomial probit regression analysis was conducted to identify the significant determinants of firms' cooperation in R&D with different potential partners. In the third phase, the simulation model of Korean manufacturing firms' cooperation in innovation was defined. The simulation model accomplished partnerships between firms, including inter-sectoral alliances. In the last phase, aimed in this study, which is built on information generated in phase three, we accounted for testing three different public 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 scenario to verify the gains (or loses) in the number of firms cooperating and networking. 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 and then by cooperation-specific sets of determinants.

It is worth to mention that, no research in the literature has 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. 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 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. We believe that this research is a good example on how to utilize empirical 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. 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 ABS models are usually visual tools and manually operated environment. 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 found in ACE implementations.

The encouraging results, 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. However, its better development and the inclusion of new entities such as research institutions and government organizations would lead to better accuracy on the generated results. The model can be generalized to include a number of extensions that 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 research questions and policy scenarios tested. Another extension tested 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. 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.

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