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Flávio Lenz-Cesar and Almas Heshmati

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서 울 대 학 교
공 과 대 학, 기술경영경제정책 대학원과정
151-742 서울시 관악구 신림동 산 56-1

Technology Management, Economics and Policy Program
College of Engineering, Seoul National University
San 56-1, Shillim-Dong, Kwanak-Gu, Seoul 151-742 ,KOREA
Phone: ++82-2-880-9140, Fax: ++82-2-880-8389

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Editor: Almas Heshmati
Professor of Economics

Technology Management, Economics and Policy Program
College of Engineering
#37-306, Seoul National University
San 56-1, Shilim-dong, Kwanak-gu
Seoul 151-742 Korea

Phone: 0082-(0)2-880-5845
Fax: 0082-(0)2-886-8220
E-mail: heshmati@snu.ac.kr

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Flávio Lenz-Cesar and Almas Heshmati[1]
Technology Management, Economics and Policy Program
College of Engineering
Seoul National University
flaviolenz@gmail.com; heshmati@snu.ac.kr

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Abstract

This paper introduces an agent-based simulation model representing the dynamic processes of cooperative R&D in the manufacturing sector of South Korea. Firms' behaviors were defined according to empirical findings on a dataset from the internationally standardized Korean Innovation Survey in 2005. Simulation algorithms and parameters were defined based on the determinants on firms' likelihood to participate in cooperation with other firms when conducting innovation activities. The calibration process was conducted to the point where artificially generated scenarios were equivalent to the one observed in the real world. The aim of this simulation game was to create a basic implementation that could be extended to test different policies strategies in order to observe sector responses (including cross-sector spillovers) when promoting cooperative innovation.

Keywords: Collaborative R&D; Agent-base simulation; Korean innovation survey;

JEL Classification Numbers: C15; D21; D85;

[1] Corresponding author

1. Introduction

Innovation networks have been approached and emphasized in many studies, especially in the evolutionary economics literature. However, few works have been done, toward modeling the processes by which these networks are formed and estimation of the outcomes and effects on innovative products, processes and firm dynamics. The complexity of the network dynamics involved and the heterogeneity of the agents make it hard to model this problem using traditional techniques.

Agent-based Computational Economics (ACE) tries to break the paradigms and overcome the limitations of classical economics through applying agent-based simulation (ABS) to study the economy as an evolving system of autonomous interacting agents. In this research, we made use of agent-based simulation to model cooperative R&D among firms of the manufacturing sector in Korea. Firms are modeled as the agents with heterogeneous behavior when cooperating, expressed on questionnaire answers from the Korean Innovation Survey conducted in 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, was the previous step on the research described on this paper (see Lenz and Heshmati, 2009). The definition of the determinants of cooperation to be used in our simulation system, required efforts on collecting appropriate theoretical background as well as conducting our own econometric analysis on the population 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 a 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; industry they belong to; among others. This "attraction" would eventually result in firm's interaction which could generate R&D partnership. The validation of this 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 the results 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 outcome and it allows us to follow to the next steps, which are to test some proposed policy strategies.

This paper is organized as follow: in session 2 we provide the theory and concepts of cooperation in innovation; a brief overview of Agent-based Computational Economics and the existing literature of its application in Cooperation and Innovation Networks. Session 3 presents the main dataset used to create the agents population, the origin of agents' behavior and the supporting empirical analysis and literature. In session 4, we introduce the simulation model and the calibration process. In session 5 we discuss and provide conclusion about the contributions of this research.

2. Theory and Practice

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 sources. As products and processes become more complex, it 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 positive impact of cooperation in innovation is strongly supported by the extensive literature (Hagedoorn et al., 2000; Powell et al., 1999; Cassiman and Veugelers, 2002; Belderbos et. Al, 2004b; Doo and Sohn, 2008; D'Aspremont and Jacquemin, 1988; Miotti and Sachwald, 2003; Czarnitzky and Fier, 2003; Sivadas and Dwyer, 2000; and others).

A wide range of academic studies consider 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, Forfás (2004) identifies a number of barriers for the formation of networks. It is incorrect to assume that the beneficial view of the cooperative behavior is enough for networks to emerge spontaneously. In order to promote networks formation and to enhance its performance, governments must be aware of the barriers and must play a major role on fostering and creating conditions for network formation and its effective operation.

In this study, we assumed that it is TRUE that cooperation in innovation activities will benefit firms in a general way, by increasing innovation output and maximizing economic growth in national level. Thus, the objective was centered on the ways to identify and 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 these two kinds of cooperation (product and process innovation) which are directly associated with innovation activities. What are the motivations and characteristics of firms that determine the firms to perform cooperative innovation? In Lenz and Heshmati (2009), we presented a broad review of studies employing regression analysis (Belderbos et al., 2004; Mark and Graversen, 2004; Miotti and Sachwald, 2003; Sakakibara, 2001; among others) in addressing this main issue, as well as our own regression analysis using the Korean Innovation Survey data. The result show that, factors such as firms' size; proportion of R&D personnel; origin; risk, cost and organizational capability constraints;

sector characteristics; profitability; among others; may affect positively or negatively on firms' willingness to cooperate with suppliers, customers, competitors and institutions.

Agent-based Simulation

Agent-based computational economics 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 agents are the small units of this artificial world where interaction and decisions take places. Agents are bounded rational, and they are autonomous and heterogeneous on their behavior. The main ingredients of ACE models are described in Fagiolo et al., 2007; Tesfatsion, 2001; and Richiardi, 2007. These include: *heterogeneity* – no aggregate level representation of entities; *autonomy* – no centralized control over individual agent behaviors; *bottom-up perspective* – aggregate outcomes (on the top) result from the individual agents' actions and interactions (on the bottom); *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 but in a much richer way which depends on modeler's definition; *non-equilibrium* – ACE models do not obey a one-shot game, where scholars observe the beginning and the end state of the game, allowing investigation along the way (the absence of equilibrium may be seen as an advantage of not having over-simplification caused by equilibrium assumptions).

AB Simulation in Innovation Networks

The capability of agent-based models to capture behavioral 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 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. Their research included a survey in a German region 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 which were calibrated in such a way as to generate "reasonable results". It is not possible to establish from the paper what was the number of agents in the simulation or whether the artificial universe of firms had its origin in the real observation. In an inter-related and similar approach, Daskalakis and Kauffeld-Monz (2007) conducted an investigation using agent-based simulation to study the dynamics of trust building in regional innovation networks. They also conducted econometrics analysis over a German dataset containing 23 innovation networks and approximately 600 participants among firms, universities and research organizations. From the empirical findings, they constructed and calibrated an agent-based model in order to simulate the dynamics of trust and knowledge transfer. The simulation game is run with 3 heterogeneous cooperating agents.

Petra Ahrweiler (University of Hamburg), Nigel Gilbert (University of Surrey) and Andreas Pyka (University of Augsburg) 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). The researches follow the concept of "*KENE*" introduced by Gilbert (1997) – some sort of genetic representation for knowledge (knowledge gene). KENEs are triples of numbers containing information of the agents in 3 elements (capability, ability and expertise) and they may be exchanged between companies. Firms exchange their KENEs in order to generate innovative products and survive in the market. Networks emerge from these partnerships. Their simulation games were implemented with imaginary firms and allowed them to observe patterns in the generated artificial worlds which were somewhat similar to real world.

Pyka and Saviotti (2000) developed a history friendly model to investigate innovation networks in the biotechnology sector. The model attempted to represent the roles of two types of firms on network formation: LDF – Large Diversified Firms and DBF – Dedicated Biotechnology Firms. They run the model for 12 imaginary firms (4 LDFs and 8 DBFs) and compared the artificial network with some existing database in order to observe network structures like average distance and centrality. They found some 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. They modeled agents as: final firms; suppliers; clients, university and research centers. From interactions among the imaginary agents, they tested the role of universities, research centers and leading firms in the Industrial District's innovation performance. Taylor and Morone (2005) developed a simulation model to study the role of supporting institutions on network formation and innovation dynamics, taking into account the geographical configuration of the province of Foggia in Italy and 32 local firms. The striking result was that "*just one 'broad' supporting institution could drastically increase the speed of convergence of the system towards the long-run steady state* (…) *increased dramatically the number of possible partners for innovations endorsing the creation of several innovating networks* (…) (which) (…), *in turn, increased the participation of small and medium firms to the partnership and, through this channel reduced the concentration of innovating activities generating a more competitive environment*".

3. Data and the behavioral definition background

The Korean Innovation Survey

The Korean Innovation Survey is carried out by STEPI (Science & Technology Policy Institute) in the manufacturing and service sectors for every three years. The 2005 version (manufacturing sector) is the one object of this study. The 2008 survey was not yet available at the time when this research was conducted. Questionnaires related to the years from 2002 to 2004 were sent by postal mail to around 4,500 firms with over 1 employees from sectors KSIC 15 to 37 (Korean Standard Industry Classification which is equivalent to the international Standard Industry Classification at two-digit level). The response rate was close to 61%. A total of 2,743 firms answered the survey, which represents a work force of about 630 thousand workers and a total turnover of 281 trillion won in 2004 (approximately US$ 280 billion) – about 36% of the total Korean economy. Mostly due to missing information, we have selected 1839 firms to be included in the regression and simulation analysis.

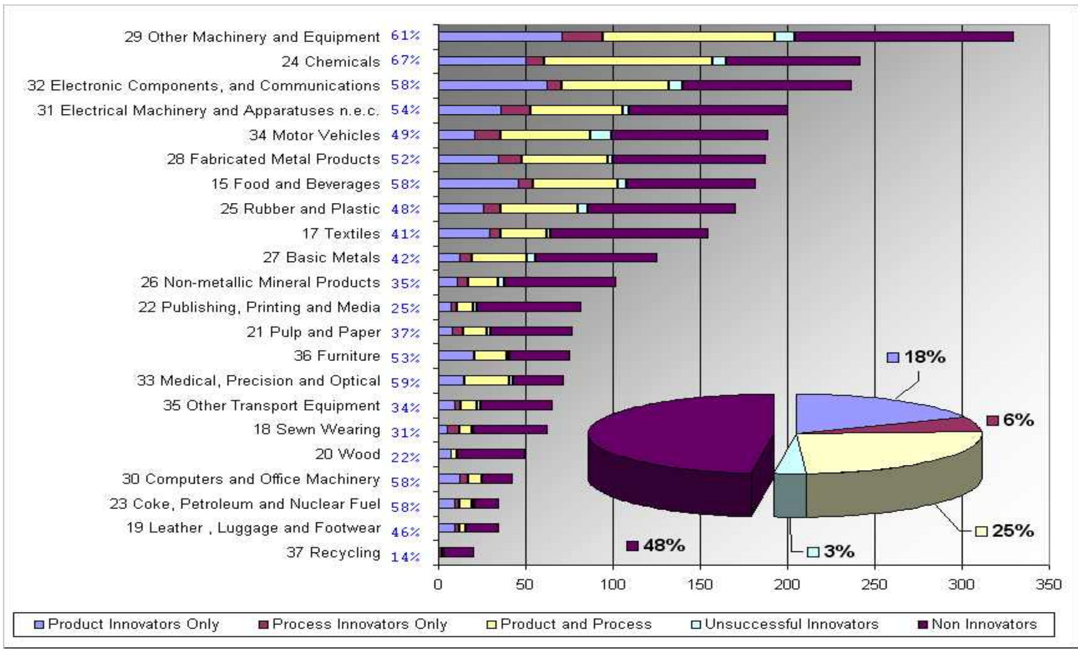

Figure 1 – Number of firms per each industry and types of innovation (% represents the share of innovative firms in the industry)

Innovation activities were conducted by 1,425 firms during the 3-year period, which represent 52% of the sample respondents as one may observe in Figure 1. Almost half (49%) of the firms successfully have conducted innovation in either product or process innovation. The most innovative industry in Korea is sector 24 (Chemicals), in which 67% of the firms have conducted innovation activities. From the point of view of cooperation, which is the object of this research, firms have answered about the percentage of contribution of internal, cooperative or outsourcing to their product or process innovation activities. Figure 2 show that, from the 1,345 successful innovator firms, 475 (or 35%) have had cooperation with external partners (including the ones with both cooperation and outsourcing), while 11% have not had cooperation, but received some outsourcing type of external contribution. More than half of the firms (54%) conducted product or process innovation activities with no external contribution (only internal R&D). The percentage of contribution of these external partners, however, was much lower. The ratio of internal development for product innovation was about 86%, while collaborative and outsourcing development contributed with 12% and 5% respectively. For process innovation, the share of internal contribution for innovation was 69%, while collaborative and outsourcing development represented 15% and 16%. Even though the contribution of external partners was still low, a significant part of the companies (46%) have already experienced cooperation in products. It means that there has been a growing trend since the previous innovation survey (KIS 2002), in which 42% of the companies answered positively whether or not they had cooperated in innovation activities.

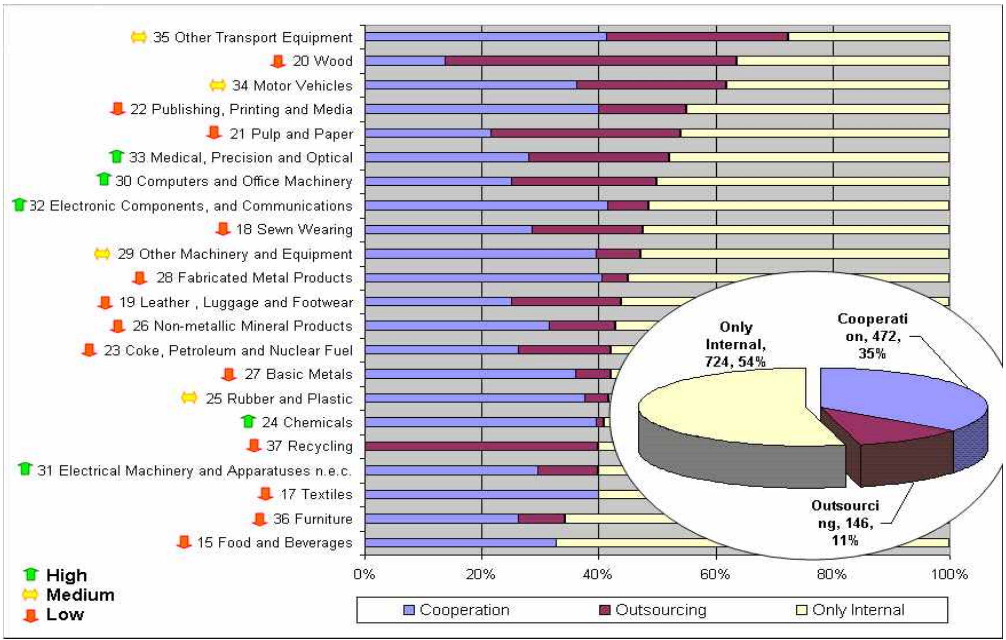

Figure 2 – Number of firms per type of external partner

Determinants of cooperation

In Lenz and Heshmati (2009), we present the econometrics model used to extract what we name "determinants of cooperation". We were mainly inspired by Belderbos et al. (2004) to define a 4-equations multi-variate probit model with a dependent variable for each kind of cooperation: with competitors, with suppliers, with customers and, with institutions. We applied an extensive regression analysis procedure in order to identify the best set of explanatory variables to account for the heterogeneity of the agents (firms) in our simulation model.

The findings included: **firms' size** affects positively in all four types of cooperation; **R&D Intensity** – measured as the proportion of employees involved in innovation activities – showed to also affect positively all four type of cooperation; being a member of one of the Korean conglomerates (the ***chaebols***) increases the likelihood to cooperate with suppliers but not with other types of organizations; **foreign** companies in Korea are not likely to cooperate with institutions and competitors but nothing can be said about suppliers or customers; as expected from the previous literature, belonging to **high-tech** sector influences firms to cooperate with competitors but it doesn't affect significantly the other three types of cooperation; for the **industry average innovation size** (average number of R&D employees of all firms in each two-digit sector, it affects negatively horizontal cooperation, while the **industry average turnover** impacts positively on horizontal cooperation and cooperation with suppliers but doesn't impact significantly in cooperation with customer which is partially in line with findings in the previous literature; **industry average profitability** appears to influence negatively on cooperation with competitors and positively with institutions, which rejects the hypothesis that higher profitability in the industry decreases the likelihood to cooperate in general; the **speed of technological change** in the sector (average percentage of participation of new products in the market compared to non-new products weighted by the firm size) as a positive and significant factor affect cooperation with customers, while, unexpectedly, it affects negatively on cooperation with institutions showing that Korean companies from dynamic sectors prefer to develop their innovation activities internally; cooperation with institutions, suppliers and customers are affected positively when firms fell **organizational capability constraints**; **risk constraints** affect positively horizontal cooperation but it does not affect any other types of cooperation while **cost constraints** seems not be a factor to determine the Korean firms' likelihood to cooperate on innovation activities.

In addition to the empirically found factors affecting cooperational behavior, we also got from the literature that **inter-industry cooperation** in innovation increases with higher commercial transactions. Sakakibara (2001) states that firms tend to conduct inter-sector cooperative R&D projects in industries that are, somehow, related vertically – i.e., either with customers or supplier. In order to define sector linkages in our simulation model, we have used an Input/Output table dataset.

4. The Simulation Model

The model was designed to run with the same dataset used in the regression analysis. Our first step was to validate the virtually generated world against the observed real world – which means – the population of firms cooperating in the virtual world must be equivalent to the population of firms cooperating when the survey was conducted. The final objective of this model is to study how government can intervene and select instruments to increase cooperation among firms in the different manufacturing sectors. The following steps of this research are to implement different types of policies on the several types of industries and observe the outcomes in terms of increasing number of firms cooperating and/or networking.

For the validation step, the initial state of the simulation contains a number of firms with no linkage among them. Running the model, the set of firms must start creating links between each other, indicating cooperative projects in R&D. After some periods of time, the pattern of cooperation created in the virtual world must converge to the same pattern of cooperation we find in the survey dataset, which we named "*natural state*".

The Agents

The agents are 1839 real firms in 16 different locations in South Korea. The agents have autonomy, social ability, reactivity and proactivity in their operation. Firms have willingness to cooperate based on their characteristics and they are constantly searching and being searched for partnership. Partnerships may be of three kinds: horizontal cooperation with competitors and vertical cooperation with suppliers and customers. The degree of attractiveness of each firm depends on several factors and the acceptance to conduct cooperative R&D depends on partner fitness as well as the internal R&D capability. Availability of R&D infrastructure and personnel is mandatory for a partnership to be established.

The Virtual World

The virtual world is one big bi-dimension board representing a social landscape where agents will interact and eventually create links with each other. Agents are randomly placed in the landscape as circles, each with different size (radio) and mass. Size defines the edges of the firm in the landscape and mass, its ability to attract and be attracted by other agents. The radio of each firm is calculated by a logarithmic function of the total number of employees and the number of employees related to R&D activities. Firms with more employees have a bigger edge implying having more area for interaction. To proxy the mass of firms, and consequent attractiveness, we used the annual turnover (also in logarithmic form).

Agents are not static on their positions. They move freely in the field, in different speeds, according to a "**gravitational field**" created by other corps. These movements do not necessarily represent that firms are moving to different locations, but rather that they are getting closer (on the social sense) to other firms that better match their cooperation patterns. Agents may not occupy the same space in the field – leaning their boundaries means hitting each other. Eventually, agents hit each other, creating a cooperative interaction among them. When firms interact, they may decide to create a partnership to conduct innovation activities or not. Partnerships emerge in the field as a link between two firms. Each firm may be involved in as many partnerships it may admit according to the constraints in the model (primarily related to availability of internal resources).

The Gravity Model of Firms Attraction

Often, agent-based modelers use N x N grid boards where each place on the grid represents the geographical location of one agent (examples in Zhang, 2003; Bonadia et al., 2007; Holanda et al., 2008; Otter et al., 2001). On those cases, the interacting agents are defined by the geographical proximity: for example, the 8 immediate neighbors on the grid. Some authors also opt to include a randomly chosen remote neighbor, based on the "small word" theory (Watts, 1999), in order to better reproduce the real world between firms' social relationships. In a quite unreal approach, it is also common to find simulation models where, in each period of time, agents may interact with all other possible interacting agents

(Pyka et al., 2007).

Firms are made by people who tend to move frequently from their location and even crossing the boundaries of their geographic region. Cooperation agreements are set between those people who often meet each other in places outside the boundaries of their corporation or geographic region. In fact, the geographic proximity may not necessarily be sufficiently meaningful to lead firms into cooperative engagements. Neighboring firms may be from completely different markets, be competitors and share no social, commercial or technological relations at all. Moreover, Echeverri-Carroll and Brennan (1999) and Rallet and Torre (2000) showed that geographic proximity is not so important as a key factor to develop innovation and innovative cooperation and that local development policy makers must develop appropriate infrastructure to encourage non-local interactions as well.

Otter et al. (2001) implemented an agent-based model that used the concept of "***attraction***" to simulate location decision of agents. They used a grid type board where firms and households move according to the attractiveness of the new position. In a similar way we proceed in our model application, where agents are placed on the board in a random way but the agents' movements do not need to obey a formal grid pattern. Given conditions we find the specified model sufficiently flexible in generating R&D cooperative patterns useful in policy decision making.

We opted to implement our model using a free board where agents' size and position are not bounded by a grid and their movement in the board is driven by a set of predetermined criteria that define some kind of attractiveness based on a "gravity equation". A gravity equation defines that two objects are attracted to each other proportionally to their mass and inversely proportional to the (squared) distance between them. This definition has been used in Econophysics, which is an interdisciplinary research field, applying theories and methods originally developed by physicists to solve problems in economics. Bergstrand (1985) conducted an empirical research in order to explain international trade with a gravity model: "*The 'gravity equation' has been long recognized for its consistent empirical success in explaining many different types of flows, such as migration, commuting, tourism, and commodity shipping*." The term "Gravity Model" in economics is usually referred to as the idea where flows of bilateral trade between two countries are proportional to their GDP (which plays the role of body mass in Newton's gravity equation) and it is inversely proportional to the distance among them (Tinbergen, 1962; Pöyhönen, 1963). Other applications of this methodology may be found for example in research areas of urban economics and health planning (Shi et al., 1997; Lowe and Sen, 1996).

In our model, the attraction forces among two firms i and j are expressed as:

$$A_{ij} = \frac{\beta_{ij} m_j}{d^{\alpha}} \ \& \ A_{ji} = \frac{\beta_{ji} m_i}{d^{\alpha}} \tag{1}$$

Attraction between firms is not symmetric. Firm i may be more attractive to firm j than firm j to firm i. The terms m_i and m_j are numbers representing the mass of the two firms.

It means that bigger firms (in terms of sales) are more attractive for cooperation than smaller firms. β_{xy} is the gravitational constant calculated for each pair of firms x, y, based on the cooperation determinants later explained in this chapter. The variable d is defined as the "social distance" among the two firms, and its associate exponent α is a calibration constant. Social distance will refer to the distance in the board calculated by firms' position. As firms start moving in the board guided by their willingness to cooperate and "mass", they tend to get closer to the ones with a better matching pattern.

Gravitational relationship between corps is N x N and grows in computational complexity exponentially. For a lower computational complexity, we have limited the number of agents that attracts each one to a number decided on further calibration. Thus, each firm is attracted by some limited number of other firms – the ones with higher attraction forces. Theoretically speaking, it is also expected that there is a limit of partners that a firm considers when searching for partnership. After having been implemented, this measure showed to increase the accuracy and dynamics of the system.

Agents Interaction

When agents hit each other in the board, an interaction event is generated. At this stage the interacting firms decide whether they will create a joint project or not. A joint project is possible if firms are willing to cooperate with each other according to their characteristics and current status. In order to cooperate, firms must have available R&D personnel that will be allocated to the joint project. The more R&D workers an agent has, the more joint projects it may create with other agents. A firm may not allocate all its R&D workers in joint projects due to the need for internal capability in order to benefit from external knowledge acquired through collaboration. If two firms establish a partnership, that means they will be naturally looking to be close to each other, but they may still continue to search other partners if they have R&D resources availability.

Interaction events are strongly dependent on the attraction forces in the gravitational field, however, agents' edge size will also influence on the number of agents it may hit. An agent's size is defined as the number of workers and number of R&D workers in the firm. A bigger number of employees is interpreted as a better chance to generate interaction events with external agents. In addition, there is also a random factor of interaction between two firms that do not necessarily attract each other, but simply because they crossed their ways on the landscape. It may be interpreted as firms with common attraction points getting closer to each other, or simply by random coincidence. Such random interaction event may generate a partnership if the parties prove to match each other. This would cover the random way of relationship among agents, which is very common in agent-based models.

Determinants of Cooperation and Attractiveness

Some determinants of cooperation were taken from the regression analysis, but others cannot be validated against the available data, for example, the region where firms search for partners. On this specific case, the geographical proximity is included as a factor with positive impact on firms' interaction.

In terms of implementation in the simulation system, these determinants are translated into some gravitational attraction factor and probability of establishment of cooperation between two partners when they interact. The willingness to cooperate is calculated for each type of cooperation for each firm as:

$$W_i^{s/c/h} = \delta_1 X_1 + \delta_2 X_2 + \delta_n X_n \qquad (2)$$

$W_i^{s/c/h}$ is the willingness to collaborate of firm *i* with suppliers, customers or competitors (horizontal cooperation). Each value is calculated individually as the summation of the factors $\delta_i X_i$. δ_i is the calibrated value of the coefficient and X_i are the values associated with each firm/sector characteristics.

For each relationship between firms *i* and *j*, the gravitational constant β_{ij} (in equation 1) is calculated as a summation of the three types of willingness's based on the matching of the firms if they fit as customers, suppliers or competitors from each other:

$$\beta_{ij} = w_{ij}^s + w_{ij}^c + w_{ij}^h \quad \text{where:} \qquad (3)$$

$$w_{ij}^s = \begin{cases} W_i^s + \gamma W_j^c \text{ if firm } i \text{ matches as supplier of firm } j \\ 0 \text{ otherwise} \end{cases} \qquad (4)$$

$$w_{i,j}^c = \begin{cases} W_i^c + \gamma W_j^s \text{ if firm } i \text{ matches as supplier of firm } j \\ 0 \text{ otherwise} \end{cases} \qquad (5)$$

$$w_{ij}^h = \begin{cases} W_i^h + \gamma W_j^h \text{ if firm } i \text{ and } j \text{ match as competitors} \\ 0 \text{ otherwise} \end{cases} \qquad (6)$$

*γ is a reducer for symmetric attraction – that is – feed-back improves attraction of firms.

The probability of two firms to establish a cooperative link (ϕ_{ij}) is defined by the ratio between the summation of firms attraction and the summation of the highest attraction in both sectors. Further experimentation showed to be more accurate that the probability obeys a minimal value ($\min \phi$) - which is set on the calibration process:

$$\phi_{ij} = \min\left(\frac{(\beta_{ij}+\beta_{ji})}{\max(\beta_{\sec_i})+\max(\beta_{\sec_j})};\min\ \phi\right) \quad (7)$$

The rules for cooperative innovation were extracted from the empirical findings described before. In addition, some other behaviors were included in the model structure; despite we had no ways for verifying them empirically in the current dataset:

1. **Smaller firms fell attracted by larger firms** – It is generally accepted, a larger firm is more attractive to a smaller firm, which leads us to accept that if the partner is bigger a firm would have an additional willingness to establish cooperative links with it;

2. **The availability of human resources in at least one of partners is a necessary condition to establish R&D partnerships** – Companies allocate R&D workers in cooperative projects, but they still must keep a big share for internal projects. Partnership between two firms that have no R&D worker available is useless, so, we will consider that there must be some share of R&D employees available in at least one of the partners. Korean data showed several cooperative firms which declared no R&D personnel. Thus, non-existence of human resources is acceptable in only one of the firms engaged in the partnership;

3. **Geographical proximity between firms increases the chances of establishing partnership among them** – The partners' location, of course, must be a fact that counts on firms' criteria when searching for partnership. It is more likely that a firm located in the same region is more accessible and easier to reach than firms located in different places. Even though we may not verify, it seems quite obvious that the benefits of searching a close partner goes beyond the fact that it is easy to find. Thus we define an additional determinant to accomplish some sort of prioritization to physical geographical proximity;

4. **Inter-industry cooperation in innovation increases with higher commercial transactions** – As mentioned before, the literature supports the vertical links to be related to existence of cooperative R&D projects.

Policies

After reaching an accurate calibration on the simulation model, we may start playing the "*what if…*" questions that agent-based models allow us to do. Questions such as: "what if the government creates benefits to firms from certain industry to cooperate with firms from other industries?", "what if the government intervene increasing capability of small firms?", "what if the government stimulate big firms to cooperate more, specifically with small and medium firms?" may be applied in the model and we may investigate how these public support and incentive factors affect the collaborative innovation outcomes.

Implementation

Figure 3 presents a snapshot of the user's experience when running the simulation program. Firms are the circle corps in the landscape and they are presented in different size. Links between firms are in form of partnerships established during the simulation game. Colors used are simply to help on the understanding of the behavior of the model and to visualize individual results discrepancies.

In the calibration step, each simulation run took somewhat around 1 minute to complete. Since random factors also play their role on the model, it was necessary to run the same calibration for several times and then extract the average result. The calibration process required to run the simulation for more than a million times in order to extract the set of parameters which would better reproduce the real world. To run this amount of processes, a single machine or human interference would have no viability. We have developed a sort of Grid infrastructure where many computers on the network were running the different kinds of simulation and posting the results in a database for further analysis.

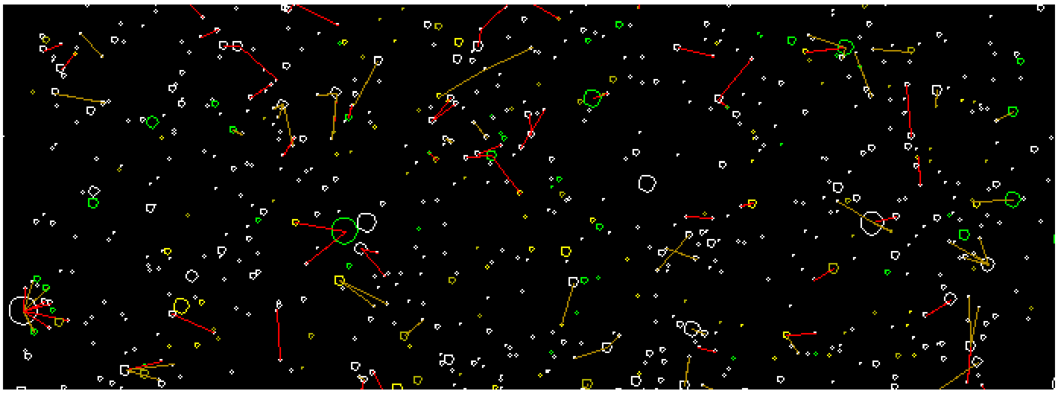

Figure 3 – Landscape snapshot

Model calibration and refinement

The calibration process consisted of running the simulation as many times as it was necessary to reach a result which was quantitatively closer to the reality. We did not expect that individual firms cooperating in the real world would be also cooperating in the virtual world, and vice-versa. In fact, many of the firms which did not report cooperation in the survey had strong characteristics of cooperative agents. This type of discrepancy may be due to some other unobservable factors that could not be captured in our analysis or even due to firm's mistake when filling the questionnaire. We were expecting such discrepancies since there are errors associated with the factors found by the regression and indeed the model cannot explain fully the sample firms R&D cooperative behavior.

The task of calibrating the simulation – i.e., of changing parameters, is one of the most important elements in agent-based simulation. Following Fehler et al. (2006), in order to adjust the system to get reasonable results that make sense on the aggregate level one must take into account not only parameter calibration but also model structure refinement. Our approach to calibration involved both tasks and at some points we had to restructure the model to accomplish other behaviors not initially defined – i.e., we had not used the Black Box approach. The model described in this chapter is the final result of this refinement. The natural starting point for the cooperation determinants, for example, was to use the same coefficients resulted from the regression analysis, while for the other parameters a good trial-and-error approach could indicate the starting point. In a search and refine approach, the parameter values have been changed and some of them could even be eliminated for some subsequent simulations. The strategy when calibrating the system was to reach a minimal level of accuracy on the aggregate number of firms cooperating on each industry. That is basically guaranteeing that the system would be able to capture the trend on the differences among industries. We mainly understand that this validation is necessary because our future policy game would basically analyze and exploit such differences.

We have run many instances of simulation with the same calibration set up to the point when the overall number of firms cooperating in the virtual world was equal to the number of firms cooperating in the real world. From this point, we have calculated the average percentage of firms cooperating on each industry. This percentage was then compared with the percentage of firms cooperating in the real observation – we have called the difference between them "***Percent Error***" (PE). The calibration producing the lowest PE is said to be the most accurate one for that industry. For each calibration set, there is one PE for each industry. The calibration process could be run for infinite number of times but we have established a stop criteria when industries with large number of firms (more than 100) would have a maximum of 5% of PE, and industries with medium number firms (between 50 and 99 firms) would have a maximum error of 10%. For industries with lower number of firms (less than 50 firms), we have ignored the results. Small industries have also a very small number of firms cooperating. Any one-firm difference easily leads to errors of 10% or even more. The search for better calibration sets was done by applying small variations on the parameters and putting them on queue again for posterior simulation by the computer grid.

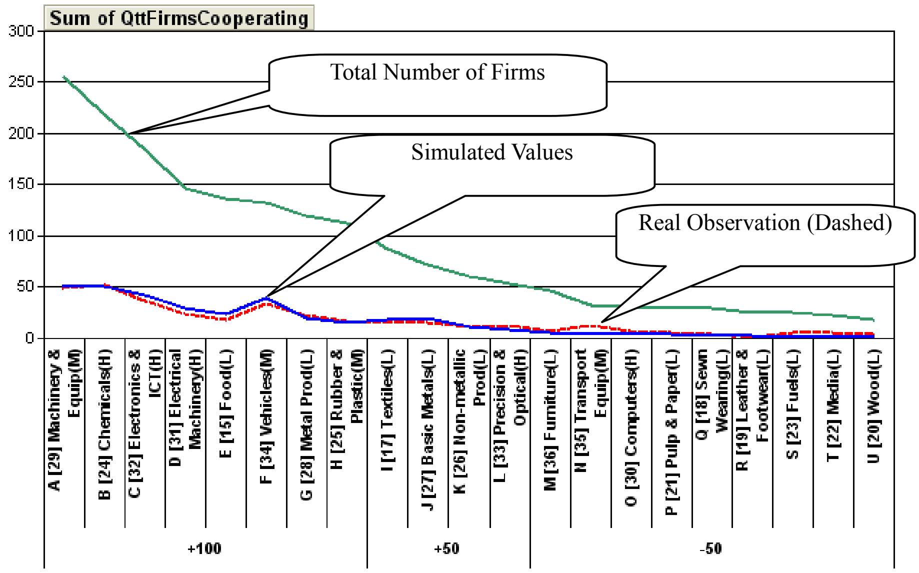

Figure 4 – Number of firms and number of firms cooperating per industry

The charts on Figure 4 ans Figure 5 show the result for the final calibration set, selected as the best among the various thousands of sets. In Figure 4, it is possible to visualize the total number of firms in each sector, the real number of firms cooperating (dashed line) and the virtual number of firms cooperating. Figure 5 displays the PE's for each industry. The axis X (Y=0) is the percentage of firms cooperating in the real world. The points represent the difference between the real percentage of firms cooperating and the virtual percentages. Negative values mean that the number of firms cooperating in the simulation is lower than the real one. The important aspect to observe here is that in industries with more than 100 firms, the error remains within the interval of 5% of the total number of firms and within 10% for industries with number of firms between 50 and 99. The model does not work accurately for 4 industries with less than 50 firms: 35 – Transport Equipments; 30 – Computers; 22 – Media; and 30 – Wood.

The model was designed from a general theory which did not make any distinction among the different industries. Also, the regression analysis captured a general behavior of the firms. When applying such general theories to individualized groups of separated industries it would be naturally expected that discrepancies might occur.

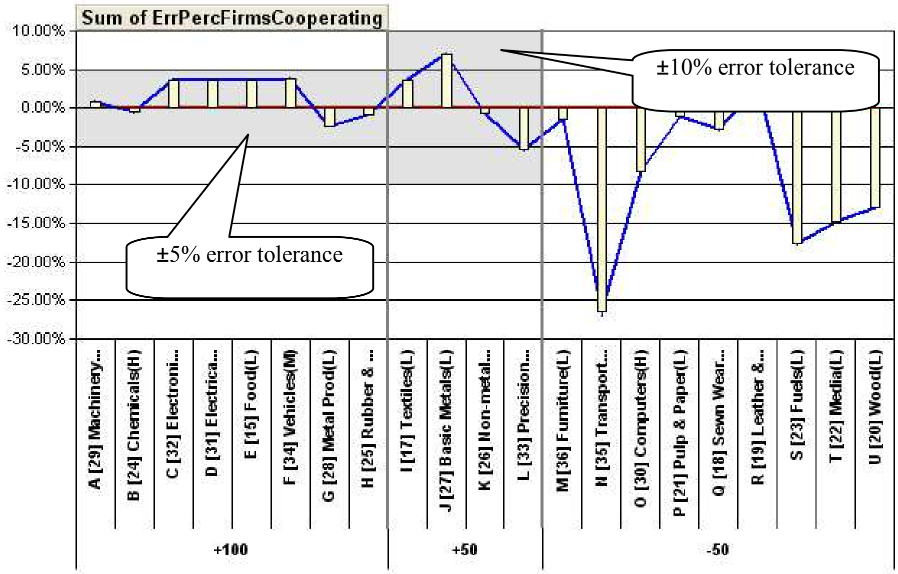

Figure 5 – Percent error for each industry (calibration set 66,882)

5. Discussion and Conclusions

In the previous session, we have introduced a simulation model which aims to reproduce firms' cooperation at the aggregate SIC 2-digit industry level. We have run this simulation through several months, demanding a huge computational effort, in order to achieve a satisfactory level of accuracy. Artificial data were compared with empirically observed stratified innovation survey data and we have shown that the model is able to capture the R&D cooperative trends on the major industrial sectors in South Korea. The validation of the model is supposed to increase the reliability of the system for the next research steps (prevision games with policy scenarios).

This study has two main contributions to the theory of agent-based simulation models related to cooperation in R&D. One is methodological: the use of real data to empirically define agents' behavior, to feed the system, and to validate the outcomes and to measure prediction error. The other contribution is on the way firms interact with each other: namely the gravitational model.

Basically, scholars who develop research output using simulation methods to study innovation networks use one of the approaches described in session 2. Using completely imaginary data, in fact, may generate any sort of result depending basically on researcher's definition of the model and its calibration. It is not really possible to test the accuracy of the system, and its validation basically depends on the author's theoretical explanation. Even though such insights may be extracted from simulation exercises like these, it is very unlikely that the outcomes may be definitely used to support policy decisions. We believe that our approach, using a real stratified dataset with large scale, may bring an extremely valid and useful contribution to agent-based simulation literature toward decision support systems for policy making.

The gravitational model of firm's interaction that we first introduced is in itself, somewhat, an innovation on how to deal with agents interaction in agent-based simulation studies. Our motivation to use this approach comes from the principle that firms find different quantity of potential partners in any place other than their own geographic region boundaries. And their behavior when searching for partners is not exactly random but obeys some sort of attraction pattern. We have performed a sensitivity analysis test in the simulation model to check whether the gravitational approach could generate reasonable results when applied alone in the model – i.e., setting all determinants to have null value or the same value for all firms. Assuming the same willingness to collaborate for all firms would lead to no difference based on cooperation determinants. Attraction differentiation would be possible only by the gravitational field. The simulation run to test the gravitational model showed to be accurate in capturing the tendency of differentiation among the industries (but not within the error tolerance). The inclusion of other determinants worked as a fine tuning to the system, increasing its accuracy when compared to the real world data.

Conclusions

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 intervention. 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 on 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.

In this paper, we describe one of three steps of this research: We have defined our simulation model of firms cooperation in innovation. Agents are 1,839 firms from manufacturing industries, heterogeneous in their characteristics and behaviors, and the outcomes accrue from their interactions in an artificial gravitational landscape. 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, equivalent industry distribution of cooperative firms, with a maximum error of 5%, when compared to the real world (for the 8 larger industries – industries with more than 100 firms). The model accomplished partnerships between firms, including inter-sectoral alliances, whose determinant was a minimal level of commercial transaction obtained from the Korean input/output table.

Further steps regards to the implementation of policy strategies which would allow policy makers to verify sector responses to government interventions. These policy drives may be applied to verify the gains (or loses) in the number of firms cooperating, number of firms networking, size of networks, number of networks, and so on. Due to limited spaces, a comprehensive analysis of the implementation of appropriate policy strategies and evaluation of their effects is conducted in a separate study.

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