Investment in Innovation, Imitation and Information Management in an Emerging Industry

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Introduction

It has long been known that economic growth is not primarily a function of capital accumulation or an increased labor supply. Rather, the major factor spurring growth is the development and use of technology. At the same time, there is a perceptible variation in the ability of economies to generate technological advancement which cannot be explained on the basis of traditional economic analysis. This has, among other things, spurred so-called "new growth theory," which seeks to endogenize the underpinnings of growth by analyzing how various assets influence technological progress (Lucas 1988, Romer 1990, Barro 1990).

There is also a growing realization that human behavior is partly a function of strategic interaction between individuals, which is explicitly elaborated in game theory. It is well-known that such interaction may exert a considerable impact on technological advancement. Once technology has been developed, society is best served by its rapid diffusion. For firms to invest in technology *ex ante*, however, they must expect to earn a rent *ex post* – before other are able to catch up. With increasing returns to scale there may be multiple equilibria, some of them suboptimal as uncoordinated behaviour may lead to all firms investing "too" little in new technology, especially longer-term generic R&D. Indeed, empirical studies have verified a major discrepancy between private and social rates of return from new technologies (Rapport, *et.al.* 1977, Mansfield, Schwarts, *et.al.* 1981, Mansfield 1985, Bernstein and Nadiri 1988, Bernstein and Nadiri 1989).

In principle, this problem can be addressed by allowing for the possibility of communication between firms (Crawford and Sobel 1982). With a lack of common knowledge about the pay-offs of other players, such communication is of no use, however (Bernheim 1984). Various studies have instead examined options for formal cooperation. Licensing of technology ex post has not been found to help, since firms are unwilling to pay for knowledge that spills over anyway (Katz and Shapiro 1986). Cooperation in research efforts ex ante similarly raises problems. For example, firms strategically manipulate knowledge, and this results in them relying on the research efforts of each other too much (Ordover and Willig 1984). According to Nelson (1988), ownership linkages are critical for firms' ability to cooperate in basic research.

A growing literature has further investigated the virtues of technology cooperation, examined to what extent it can be expected under various circumstances and how it can be improved through appropriate policy (Teece 1986, Mowery 1988, Hennart 1988, d'Aspremont and Jacquemin 1988, Ohmae 1989, Badaracco 1991, Watkins 1991, Suzumura 1992, Quintas and Guy 1995). Government programs in the United States, Japan, the European Union and individual European countries have explicitly sought to coordinate effort in order to avoid duplication and create synergetic benefits associated with economies to scale and scope.

At the same time, there are many empirical studies indicate that technological spillovers and information trading occur through informal corporate linkages rather than contract arrangements. Such diffusion would be influenced by specific factors of each economy, as well as on firm behavior. Determinants include players' competence in receiving technology from others (Eliasson 1986) as well as their ability and efforts to retain own technology to themselves (Zucker et al. 1995). In this respect, firms appear systematically different in varying set-ups, and these set-ups have come into existence as unintended consequences of previous interactions. For example, Japanese firms have been argued to pick up and capitalize on already existing technology as well as share knowledge among each other to a higher extent than U.S. firms (Aoki 1988). Within the U.S., however, major differences can be observed. Some extremely innovative clusters, which arose in the 1980s, have been characterized as follows:

> Firms in both of these areas grew out of the local university communities. The founding entrepreneurs came from the faculty and research staffs of Harvard, M.I.T., and Stanford. . . . More important, however, the universities have served as the organizing center of intellectual communities for the employees in this industry. Here engineers and scientists employed in separate, often competing enterprises can share ideas, seek advice, and come to respect one another for the creativity and elegance of their innovation. . . . Thus, the university campus is like the corner café where Italian artisans solve one another's problems and share – or steal – one another's ideas." (Priore and Sabel 1984: 287)

Indeed Italy provide other examples of mutual disclosure of valuable knowledge between firms (Piore and Sabel 1984).

So far, little effort has been made to unravel what fundamental factors account for such discernable country-difference in firms' tendency to transfer technology informally. The underlying determinants may both explain a major part of the observed country differences in the strength and direction of technological progress, and be of policy relevance. The appropriate policy response is likely to be crucially influenced by the specific stable states which characterizes a certain economy..

As one step to fill the gap, this paper examines how strategic interactions may influence firms' behavior with respect to technology. We will explicitly examine how strategic interactions between firms influence their behavior with respect to innovation, the sharing of information, and learning from each other. This paper will develop a computer simulation model based on a highly simplistic two-firm framework in which players interact given discrete choices. Except for the decision of whether to invest in new technologies, firms encounter the choices of whether to make the efforts necessary to keep new knowledge secret, to learn from others, or to imitate others.

The model will produce a range of conditions that determine whether firms have a tendency to hide commercially valuable information in connection to the R&D strategies that each player pursues. Against conventional wisdom, the model will show that, under certain conditions, competitive interaction among players brings about an economy in which otherwise commercially valuable information is not confined to the creaters themselves. This is not because of the spill-over effect assumed by Grossman and Helpman (1991) and others, but because of the incentives that each player has during the interaction. In this particular sense, "competition" creates "cooperation" in that sharing information among competitors is one form of cooperation.

Simulating the dynamic of information management with respect to investment in innovation, it will be shown that the economy reaches a stable states where cooperation co-exists with competition under various circumstances. The study moves on to make comparisons between the different stable states in terms of their economic performances. Finally, policy implications are briefly discussed.

The Model

The simulation model has two parts, multi-player local games and an "cell-automaton" simulation based on the local games. With respect to cell-automaton, we have 400 population in the simulation model. Each player has 8 neighbors with whom and only with them it directly interacts. The nature of the direct interactions with the neighbors is described as a series of multi-player local games as will be explained in the following sections.

Let us name one habitant in our simulated world "Simulacrum" and A's neighbors from "n1" to "n8". At first, Simulacrum plays an economic game in n1's territory, i.e., n1's market if there is any, and receives its return. Then Simulacrum plays in n2's market and receives its return, then in n3's market and so on. When Simulacrum finishes the game in n8's market, the return of that turn for Simulacrum is determined as the aggregate of the 8 games. In the last part of this section we will further discuss about properties of cell-automaton simulation games.

In each multiple-players local game, we have nine firms, each of which decides whether to produce its own specific goods/services or not within an economy with differentiated markets. For simplicity, all firms are assumed to be symmetrical, meaning that each firm has the same economic abilities and conditions, encounters the same strategies, and has the same potential payoffs.

Innovation spawns an opportunity to exploit a rent either by creating a new market, as in the case of product innovation, or by devising a new method of production as in the case of process innovation. In the former case, a new market is exploited where price competition has not yet started or has not yet brought the profit margin to minimum level, thus allowing the innovator increased returns. In the latter case, a rent is cultivated in the traditional market where the process innovator owns unique (typically variable) cost advantage which others do not have. Either case allows the innovator to gain the competitive edge over others which brings about economic rent or profit. Here the model reflects the case of product innovation where a rent originates on the revenue side, while in the case of process innovation it should rather appear on the cost side. In other words, innovation creates a new profitable market. This new market may invite free riders, i.e., imitators.

Though new markets can only be created by innovation, the rent that the new market provides may invite the competitor to follow the innovator. In our model, the other firm may enter the market of the competitor through learning from its technology. When the follower enters the market, the rent is equally shared by all firms in the market, which is not a favorable situation for the incumbent innovator. One way that the innovator can discourage the follower from entering the new market is to hide its newly developed technology. Concerning the nature of technology, of knowledge in general, maintaining secrets is a costly activity, but it gives the innovator a chance to cultivate the rent fully if they can successfully hide the critical technology from the eyes of the competitor. Even if it does not succeed in completely hiding the technology, such efforts to keep the secret may contribute to the relative competitiveness of the innovator.

Components of Strategies

In each strategy, there are three components available to each player. They are: "innovation," "learning," and "secret-keeping."

Innovation

In this paper "innovation" is the component which is geared toward investment in R&D, aiming to create new knowledge which enhances the competitiveness of the player and allows for the set-up of an innovative market. A straightforward, abstract, and broad definition of "innovation" is used, thereby including both radically new product innovations and incremental product refinements which becomes closer to the concept of process innovation. However as we have argued above, the effect of process innovation should be reflected in the reduction of production costs whereas it is the price that would be affected by the product innovation. We do not consider the process innovation explicitly in our model for the simplicity, though it is not difficult to expand our model to include the effects of process innovation.

Learning

"Learning" represents a different type of R&D and it differs from "innovation" in one crucial aspect. "Learning" is possible only when there is someone/something to learn from, which is not the case in "innovation". The "innovation" and "learning" components are similar in that they require the player be able to master a certain knowledge, technology, or management style that is new to it. The difference affects the societal outcome directly and indirectly through the interactions among players.

Although, the costs associated with "learning" are somewhat similar to those of "innovation," since these activities are virtually undertaking the same function for the firm, there might be significant difference in terms of the relative make up of the costs. For instance, the costs associated with searching for a new technology is an important factor for a learner. The economic situation that we deal with is such a condition where "search cost" matters. The cost necessary to find the relevant knowledge is dependent upon the choice of strategies by the players. If the firms in general are more oriented towards "learning" than idiosyncratic "innovation," it will make the search cost higher. At the same time the fact that search cost is a major cost factor for a learner makes the learner's behavior seem more opportunistic than that of an innovator who is destined to behave consistently in the long run.

In our model, we have assumed that the each size of markets, i.e., demand for innovative products are determined by the general activity level of the population. Because newly start-up ventures with new products has no resources and experiences inside to make projections for the future demand of its products, but relying on the external conditions and activities of competitors in the same industry. In other words, expectations and activities of competitors influence the level of expected demand.

An innovative market requires the existence of at least one "innovator" who creates new knowledge. This new knowledge, or technical information in its broadest definition, is costly to create as well as to learn. There is no well-developed method to learn brand new technology, and the costs associated with it can be relatively high. On the other hand, there are types of technology that are easy to learn. For instance, if the technology concerned is a part of standardized industrial education such that the pedagogical methodology is well developed and formally explained in standard textbooks.

Secret-keeping

A player who employs the "secret-keeping" component in its strategy bears the costs of hiding valuable information from the competitor. Thus it can be seen that "secret-keeping" is an important element of "information management" in a firm. Certain types of information such as product concepts are more directly related to the immediate outcome of business. Once a product concept is revealed, the advantage the concept creater possessed quickly disappears through enhanced competition in the market.

Other information, such as the cost structure of a product, is less directly related to the immediate business outcome, but nevertheless it is strategically valuable commercial information. Knowing the competitor's product cost structure enables a firm to calculate the likely outcome of a price war, should it decide to enter the market, with less uncertainty. Concealing such types of information indirectly discourages potential competitors because it is likely to increase the risk premium necessary for the new entrants.

"Secret-keeping" deters the potential competitor by piling extra costs upon it, i.e., entrance barrier. The extent to which the player who employs "secret-keeping" succeeds in using the secret keeping as an effective entrance barrier or not, however, depends on the conditions under which the players are operating as well as the other player's choice of strategies.

Secret-unveiling

Secret-unveiling is supplementary activities that are needed to overcome the competitor's "secret-keeping" efforts. Thus cost secret-unveiling is incremental cost to "learning" subject to other player's choice of strategy. When the other player employs a strategy that contains secret-keeping component, a leaner has to bear the cost of secret-unveiling before it can start learning. We introduced the concept of "secret-unveiling" to explicitly analyze the strategic interactions regarding the information management.

Strategies

Each player chooses a strategy which consists of one or more of the components at a time. There are eight strategies, of which six strategies are economically sensible in our model:

I. Full-fledged (innovation, learning, secret-keeping)
II. Student (innovation, learning)
III. Arrogant (innovation, secret-keeping)
IV. Professor (innovation)
V. Imitator (learning)
VI. Idle (nothing)

Two additional strategies – (learning, secret-keeping) and (secret-keeping) – are meaningless from an economic perspective in our set-up, since by definition there is no commercially valuable secret to keep in those cases.

Structure of the Multiple-Players Game

Players are unable to make binding commitments and this setting forms a non-cooperative game. We also assume that each player chooses a strategy which will maximize its own profit.

We assume complete information, meaning that each player know its counterpart, as well as all actions and all potential outcomes available to both of them. Perfect information is not assumed for the time being, and the other player's actions are not observable at each state. At the end of each stage all actions taken are disclosed and will be used to determine the strategic choices in the next turn. Thus multi-players game in this model represents a multi-stage game with observable actions.

By definition, "innovation" occurs prior to "learning". In the first stage of the game, each firm determines simultaneously whether to "innovate". What happens to the market of a player who decides not to "innovate" in the first stage? The answer is that that player refrains from creating any new knowledge; it prefers to depend on others.

In the second stage, the each player decide whether to try to keep the fruits of innovation secret or not. This consideration arises spontaneously whenever a player employs any strategies of which "innovation" is a component, as it must then decide how to control the result of that innovation.

In the third stage, the decision whether to learn is made. Again, this is equivalent to the decision whether to enter into the other player's market or not.

In the fourth stage, profit maximizing outputs are determined by each firm simultaneously. Thus we now have a situation characterized by Cournot competition.

Payoff functions

The incentive for any innovative activity is the prospect of enjoying a monopoly position in the newly created market. The presence of a rent encourages other firms to enter as well, however. To illustrate the interaction between innovator and follower, both "rent-seekers", let us postulate that

$$P = D - q$$

Where p and q represent price and quantity respectively, and D is demand which will be more specified in the full version of the paper. Demand and quantity are both non-negátive and constitute revenue side of the payoff function.

On the cost side of the payoff function, the expenditures required for "innovation," and "secret-keeping" are denoted CI, CS, respectively. Regarding the cost of "learning," cost of secret unveiling, CU, is incurred additionally if the counterpart tries to keep its information secret. Learning the new technology that others innovated requries one more step than otherwise would be needed if the innovator tries to keep the technology secret.

Some Specifications of the Model

Demand Function

Demand for each player is given by the demand function with following characteristics;

D = f(number of idle players)
where $f<0$ and $f'>0$

This demand function shows that the demands for products that each player produces are given at the activity level of the industry. It implies that each player does not have reliable source of information for the future demand of the products that it is going to innovate/imitate. Such situation is not unusual for the innovative products since there is no comparable preceding products in the existing markets.

Cost of Innovation and Number of Non-secret Keepers

Cost of innovation is a function of the general atmosphere of the industrial region. If there is a custom to give advice each other in the daily informal meetings, e.g., chat over coffee, then we are likely to see the reduction of innovation cost in general, whereas innovation cost is likely to be kept high when people distrust each other and take hostile behavior. We take the number of non-secret keeper, i.e., those who do not use strategies that contains secret-keeping behavior, as a surrogate of the general atmosphere. The higher the proportion of non-secret keeper with respect to total number of the population, the more friendly it is likely to be, i.e., innovative activities are more likely to be less costly.

α =f(number of non-secret keeper)

where f<0 and f'>0

α is a surrogate of the information flow in the local area

Secret Keeping and Secret Unveiling

Though we have introduced the cost of secret-keeping and the cost of unveiling secret in our model, unfortunately nothing much is empirically known about the nature of those costs, and less about their relationships.

The cost of secret-keeping includes such costs as contracting, monitoring, and enforcing costs to keep workers' mouths shut, or to keep critical persons royalty to the firm high. And also there has to be rules about the handling of internal information, and internal auditing office to check the compliance with those rules, and so on. The secret-keeping cost includes the incremental cost incurred to provide employees motivation to voluntarily comply with the company's rules.

The cost of secret-keeping can be conceptually divided into two parts; fixed cost and variable costs. Though they are often difficult to distinguish in reality and depends upon the scope of product definition and time horizon, it is useful to distinguish them because they have different effects upon the secret unveilers.

The cost of secret unveiling are reverse engineering costs, search costs for useful information, industrial intelligence activity costs, and other similar activities. We do not know much about the nature of these costs and for the sake of simplicity;

Cost of Secret-unveiling = Cu (Cost of Secret Keeping)

where Cu is exogenously given.

The diffusion of information is typically taken for granted as a natural course of events in many economic growth models. In these models the rate of diffusion is exogenously given. On the contrary we explicitly analyze the effect of information management, i.e., secret-keeping cost and secret-unveiling cost in our model, in the economic performance of the economy. Implicit assumption in our modeling is that information management affects the rate of diffusion in the economy.

However, information management does not always guarantee the success. Its success is conditioned to the economic interactions with competitors and to the extent the nature of information itself. For instance, it is more likely that hidden secrets are discovered and diffused in public, without intentional efforts to unveil secrets, as the quantity of the product increases. The variable cost of secret-keeping is intended to forestall such "natural" process of information diffusion. Since variable costs are more closely connected to the nature of knowledge and information, the actual interaction between the secret-keeper and the secret-unveiler is more likely to be found in the organizational and legal cost side.

An Illustrative Case of the Simulation: the effect of local information flow

In our setups, students and professors are least immune to the threats of being imitated. Professors concentrate their efforts only in innovation, and do not bother to hide their valuable information nor to explore other markets. Similarly, students do not invest in secret-keeping. They are vulnerable to the existence of free-riders, i.e., imitators.

However vulnerable, they are socially desirable strategies. From the societal point of view, the secret-keeping component is justified only to the extent that it encourages innovation. Therefore, it is socially preferable if innovation could be pursued without incurring additional cost of secret-keeping.

Let us briefly show a result of simulation when cost of innovation with respect to the local number of secret-keepers gradually increases. (See figure 1) In this example, we have "Student" as the dominant strategy at first. Then as the cost of innovation with repect to the local number of secret-keepers increases, we see the number of imitators increases, followed by idles. Around 23000 of the horizontal axis, we have "imitator" as the dominant strategy, which is replaced by "idle" around 30000.

(This paper is limited to the introductory purposes and the details of the simulation games and results are presented in the full size version of the paper)

The number of strategies with respect to Ca