AN ANALYSIS OF A RESEARCHERS' BEHAVIOR IN SEMICONDUCTOR LASER DIODE TECHNOLOGY: AN R&D COMMUNITY PERSPECTIVE

By

Watchara Tong-ngok

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To Boon and Pramual Tong-Ngok
and
The Tong-Ngok future generations

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CHAPTER I

INTRODUCTION

1. Introduction

As global competition intensifies, organizations need to enhance their innovation capabilities. Technological innovations have been determined to be powerful forces for industrial development, productivity growth, and are the major driving forces for the economic development of nations (Abernathy and Clark, 1985; Porter, 1990). Policymakers and business planners in organizations (e.g., government organizations and private organizations) locate and conduct appropriate methodologies to stimulate, maintain and increase their innovation capabilities.

In a highly competitive environment, leadership organizations achieve competitive advantages through acts of innovations (Porter, 1990). Therefore, *innovation* is a key role for the future success of organizations. Generally, innovations are R&D's output. How are innovations created in R&D? Many scholars accept that innovations are developed from the cumulative efforts of scientific and technological knowledge (Malerba, et al, 1997; Teece, 1996; Saviotti, 1995; Van de Ven, 1986, 1993; Ayres, 1988).

Based on two conceptualizations of the process of technological change, creative destruction and creative accumulation concepts, technology leading organizations and/or nations and their competitors need to achieve and increase their innovations[1]. Individuals

[1] Creative destruction and creative accumulation concepts are discussed by many scholars (Malerba, et al, 1997, Pavitt and Patel, 1994; Pavitt, 1988, Dosi, 1988).

or organizations that have more scientific and technological knowledge have better opportunities to create innovations. However, innovation management is complex. How can individuals or organizations maintain their innovation capabilities for longer periods?

A great number of literature studies involve innovation processes and/or innovation systems (Afuah, 1998; Bates, 1995; Abernathy and Clark, 1985; Abernathy and Utterback, 1978), however, only a few groups of scholars focus on the persistence of researchers and/or organizations, e.g., Malerba, Orsenigo, and Peretto, 1997; Rappa and Debackere, 1995; Debakere, Clarysse, and Rappa, 1992; Rappa, Dabakere and Garud, 1992; and Debeckere, Rappa, and Clarysse, 1995. Most of these scholars are interested in the persistence of researchers in an emerging technology. How is the persistence of researchers in well-developed technology?

A well-developed technology is an existing technology that has been developed for many years. During this period of time, other technologies are also being developed. Some researchers or organizations turn to other technologies, some do not. It is interesting to study factors that affect the persistence of researchers in an R&D community. Furthermore, we may learn patterns of a persistence behavior by studying members' behaviors in the R&D community.

Such patterns are worth studying because policy makers and business planners in non-technology leading countries and non-technology leading firms need to know the patterns as technology followers. When they know more about the patterns, they are able to set their strategies more appropriately. One may question whether influential factors of persistence in an emerging technology and a well-developed technology are the same. It is possible that some of them overlap.

As an example, we may consider the death factors of thirty-year old men and one-year old children. Considering the same factor (e.g., disease), children may get Acquired Immunodeficiency Syndrome (AIDS), a virus (HIV- Human Immunodeficiency Virus) at birth. Men may get the HIV from their behaviors or blood transfusions, etc. With regard to different factors (e.g., accidents), though children do not drink and drive cars, they can be victims of a drunk driver, yet many adults drink and drive cars may or may not cause accidents. Thus, we see some factors which overlap. Therefore, we are interested in studying factors that affect the persistence in a well-developed technology.

Scholars use the word "persistence" in a different environment. It depends on their objectives. Although this dissertation is inspired by the studies of other researchers, the study is still unique. Therefore, we have to set a frame of "persistence" in our study. We will examine unexplored facets of persistence.

2. Persistence Defined

Bowen (1987) states that persistence is possible when failure is not obviously indicated. He also states that ambiguity of the final outcome has several causes. They may come from: (1) lack of measurability, (2) lack of goal clarity, (3) cognitive limits on information processing or biases in interpreting feedback, (4) temporal and hierarchical factors associated with goals, and (5) when negative feedback is combined with positive feedback.

Polley (1991), on the other hand, employs "persistence" in his study in a case of receiving only negative feedback, but still continuing to work. His study was used to create a computer business game to test investor's persistence. Based on the game's conditions, investor players receive identical funding and feedback since causes of ambiguity are considered. Therefore, the game still provides "unrealistic" conditions.

Szulanski (1995) uses "stickiness" to investigate barriers to transfer the best practices inside firms. He states that stickiness is developed from characteristics of knowledge transferred and from characteristics of a situation. He identifies that characteristics of the knowledge transferred are: (1) casual ambiguity and (2) unprovenness. The seven characteristics of the situation are identified as: (1) a source that lacks motivation, (2) a source that is not perceived as reliable, (3) a recipient that lacks motivation, (4) a recipient that lacks absorptive capacity, (5) a recipient that lacks retentive capacity, (6) a barren organizational context, and (7) an arduous relationship between source and recipient.

Another important condition of persistence is the redundancy of the opportunity to withdraw or choose an alternative (Brockner and Rubin, 1985). We may consider a prisoner as not being an example of persistence because a prisoner has no opportunity to get out of his environment physically. Generally, researchers have choices - to do their work, to change their field of interest entirely or to quit. Therefore, this condition is considered to a field observation.

This definition of persistence is stated with Brockner and Rubin (1985); Bowen (1987); and Szulanski (1995). The only exception is Polley (1991). Persistence in this dissertation is any decision to continue responding to something after getting feedback. Persistence measurement is a period of time that one does his/her works/activities in a given environment. Some scholars use "contribution span" as a persistence measurement (Rappa, Debackere, and Garud, 1992; Rappa and Garud, 1992). The contribution span is defined as the time span between the first and the last literature that one contributes to a given community.

Staw and Ross (1987) state that determinants of persistence are derived from psychology, social, and structural factors. In high competitive environment, individuals or organizations get feedback from a variety of sources. Therefore, many factors may affect the persistence of researchers or organizations in an R&D community. In order to clarify our study; we have designed our units of analysis using three levels:
(1) individual, (2) organizational, and (3) national levels.

3. Persistence – A Field Observation

Dunphy, Herbig, and Howes (1996) state that the critical path of a successful industrial innovation is made up of a number of macro and micro level discriminators[2]. This research observes the persistence of individuals, organizations, and nations. We believe that each unit of analysis has some specific factors that affect the persistence. Hypotheses are developed in each unit of analysis based on literature reviews.

Generally most researchers who contribute their knowledge to the R&D community are scientists and engineers working for governmental laboratories, universities, and private companies in different geographical locations. However, these scientists and engineers have specific characteristics. They need to be independent, creative, ambitious, self-motivating and self-managing (Tingstad, 1991; Miller, 1995; Drucker, 1974). However, some other factors may affect their persistent (e.g., technological characteristics and social status).

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[2] Dunphy, Herbig, and Howes (1996) consider global, national, and industrial as a macro level and firms as a micro level.

It is also known that an organization has its own characteristics and environment. The types of organization and its location may affect its persistence. The presumed conflict between the researcher's autonomy and organization's goals is a theme in R&D management literature (Badawy, 1991; Whittington, 1991; Gunz and Gunz, 1994; Debeckere, Rappa, and Clarysse, 1995). The conflicts may affect the persistence of both researchers and organizations.

A nation consists of people, culture, economic structure, national values, regulation and history. Ralston, et al. (1995) states that a national culture drives work values. A government is expected to be the facilitator or inhibitor in a research process (Hurley, 1997). It has been widely documented that nations have different types and rates of technological change (Nelson, 1993). Thus, we believe some other national characteristics may affect the persistence of nations in a given technology.

According to the innovation concept and a process of creative accumulation concept of technological change, if researchers do not persist in a specific field of technology, it will affect organizational performance. Management needs answers to such questions as: How can researchers in the high-tech industries persist in a specific research topic? What influential factors have motivated these researchers to persist in their work?

Furthermore, management also needs answers about their organizations in order to survive in a competing environment. Some interesting questions are: How can organizations persist to conduct research in a specific technology? What are the influential factors that affect their organization persistence? Once the management receives answers, they can set appropriate strategies to improve their innovations.

This dissertation will study a researcher's behavior in a high-tech industry. The Semiconductor Laser Diode technology has been selected as our focus. This technology has been developed since 1966. Products have been introduced into the market for almost 20 years[3]. Semiconductor laser diodes are used in a variety of products such as: compact disc (CD) players, CD-ROMs for computers, and laser printers. It is a very well-developed technology. The semiconductor industry has claimed that it has advanced at a rapid pace while the industry grew internationally (Almeida, 1996).

4. Research Area

As mentioned earlier, a few groups of scholars are interested in the persistence of researchers and/or organizations (Malerba, Orsenigo, and Peretto, 1997; Rappa and Debeckere, 1995; Debekere, Clarysse, and Rappa, 1992; Rappa, Dabekere and Garud, 1992; Debeckere, Rappa, and Clarysse, 1995). Malerba, Orsenigo, and Peretto (1997) present that *an innovative intensity* factor affects the persistence of organizations. Rappa and Debackere (1995) present that *an early entrance* factor affects the persistence of researchers. Debekere, Clarysse, and Rappa (1992) present that *a network of ongoing collaboration* factor affects the persistence of organizations. Rappa, Dabekere and Garud (1992) present that *a market size* factor affects the persistence of organizations.

Most studies are interested in emerging technologies (Rappa and Debackere, 1995; Debakere, Clarysse, and Rappa, 1992; Rappa, Dabakere and Garud, 1992; Debeckere, Rappa, and Clarysse, 1995). They study whenever a researcher quits from the R&D community. It is reasonable that policy makers or business planners are

[3] Sony and Philips have sold CD players to the market in 1982 (Wood, 1995).

interested in this topic because they can make decisions on whether they will support the emerging technologies.

This dissertation focuses on the persistence of researchers, organizations and nations in a well-developed technology. Studying the persistence of researchers in a well-developed technology enhances our understanding about their behaviors through their publications. This leads to learning a pattern of persistence of each unit of analysis in the technology. Since we know the pattern, we can predict their behaviors.

We are interested in using a bibliography database in our study because it provides rich information entries such as authors, their affiliations, the titles, dates of their publications and more. Nowadays, many electronic databases are provided in institutions (e.g., universities and firms). For example, professors and students can use electronic databases easily and conveniently in universities. There are many types of electronic databases such as financial databases, bibliography databases, etc. Generally, though, bibliography databases are used in universities.

We also test the validity of a "bibliotech" technique. The "bibliotech" technique is a technique that uses bibliography data in order to study more specific topics. However, bibliography data has a limitation. It does not provide the researchers' age, their education, financial support for their research and so on. Additionally, there are many bibliography databases in the market. Each bibliography database has its special characteristics. For an example, one provides type of publication (treatment) but others do not.

Some influential factors that affect the persistence of researchers and/or organizations have been studied in an emerging technology. One may have questions about whether all influential factors that affect the persistence of researchers and/or organizations have been studied. We emphasize that we will study persistence behavior of members in a well-developed technology. Some of them may overlap each other but are still different to a certain degree.

When we consider those studies, we find that some factors may affect the persistence of researchers or organizations in an R& D community. Therefore, can other factors such as researcher's motivation, technology characteristics, geographical location, and/or types of an organization affect the persistence of researchers, organizations and/or nations?

5. Research Questions

The questions investigated in this research are:

a. Can bibliography databases be used as a tool to study the persistence of researchers, organizations, and nations in an R&D community properly?

b. What are influential factors that affect the persistence of a researcher in an R&D community?

c. What are influential factors that affect the persistence of an organization in an R&D community?

d. What are influential factors that affect the persistence of a nation in an R&D community?

CHAPTER II

LITERATURE REVIEWS

1. Scientists and Engineers in Research & Development

Research and Development (R&D) is used to describe a segment of any organization in which the creative and innovative work is done (Pegels and Thirumurthy, 1996; Miller, 1986; Constant, 1980; Crane, 1972). Generally, not only scientists and engineers work with R&D projects, but also technicians (assistant scientists or engineers), associate scientists, programmers, accountants, artists, and management people (Tingstad, 1991; Miller, 1986). It is known that innovations are R&D outputs.

Scientists and engineers have to work with other professional workers in R&D, however, it is known that scientists and engineers are the main group in R&D projects. The other "professional" groups are staff in R&D projects. When scientists and engineers publish papers, they put only their names in their area literature. Therefore, this study focuses on scientists and engineers' behaviors whose names are in their papers or documents. It is possible that there are technicians or other professionals' names in the papers or documents. Our assumption is that all names in the papers or documents are scientists and engineers' names.

Scientists and engineers need to be independent, creative, ambitious, self-motivating and self-managing (Tingstad, 1991; Miller, 1986; Drucker, 1974). Conflicts occur between the need for freedom on the part of scientists and engineers and the need for control on the part of an organization (Miller, 1986).

Van de Ven (1986) states that one of four central problems in the management of innovation is the human problem of managing attention[1]. He describes that it is difficult to convince trigger people (i.e., scientists and engineers) to pay attention to new ideas, needs and opportunities. A constant free flow of ideas and directions are important conditions in innovation. Without such a free flow, an organization will lack choices and options for its future (Jenilek and Schoonhoven, 1990). Therefore, scientists and engineers need not only good technological instruments, but also better motivation in order to work efficiently.

2. Information Processing in Science and Technology

How do researchers obtain knowledge? Allen (1988) presents an information process model in science and technology as presented in Figure 1. In this figure, scientists in the science system receive information (input) through a variety of methods (i.e., talk with each other and read the others' papers). Once they consume information, they transform and produce their knowledge through their tangible products, e.g., scientific papers. In the technology system, engineers must first understand and formulate a problem confronting them and then select appropriate information through a variety of methods and resources. Once they solve their problem, they transform and produce their products – physical hardware in the form of hardware, other products, and documentation.

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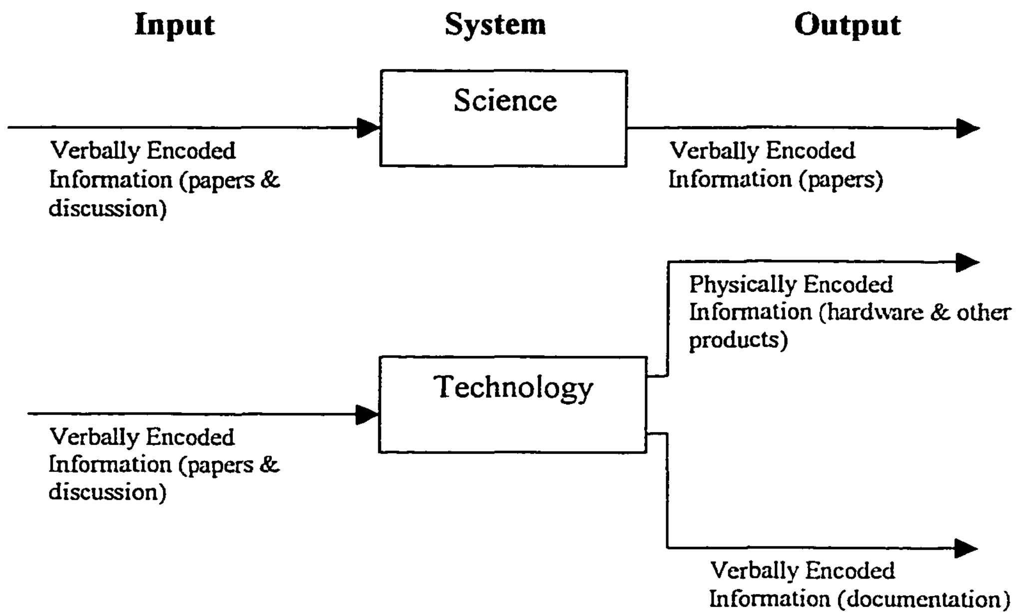
[1] The central problems are (1) human problem of managing attention, (2) process problem of managing ideas into good currency, (3) structural problem of managing part-whole relationships, and (4) strategic problem of institutional leadership.



Source: Allen, Thomas, "Distinguishing engineers from scientists." In Managing Professionals in Innovative Organizations. Ed. by Ralph Katz, Ballinger Publishing Co., 1988, p.9.

Figure 1: An Information Process Model in Science and Technology.

Allen (1988) also states that the scientist's goal is a published paper whereas the engineer's goal is to produce physical products. We observe that many types of treatment (i.e., theoretical and new application papers, theoretical and experimental papers, and experimental and practical papers) are classified in published papers. Practically, it is difficult to identify the scientist or engineer from examining their products, especially their papers or documents.

Because of the complexity of R&D, Bhattacharjya (1996) states that, "R&D is not a homogeneous activity but one that comprises diverse activities such as basic research, applied research, and development with complex interrelationships amongst them."

Therefore, this study use "researchers" instead of "scientists and engineers" in later parts of the study.

3. An R&D Community

Both products of science and technology systems are published and contributed to the public. Most papers and documents are published in academic journals, conference proceedings, and magazines. On the other hand, physical products are mostly patented, which can take years. Generally, many database providers keep these documents and papers systematically. However, they do not keep physical products. Therefore, most products of science and technology systems can be traced.

Once the papers or documents are published or presented to the public in any media, a group of scientists and engineers, or individuals who are interested in the same field of knowledge are very likely to study the new literature. This activity is called an "invisible college" (Ziman, 1987), or a "researcher community" (Rappa and Debackere, 1992).

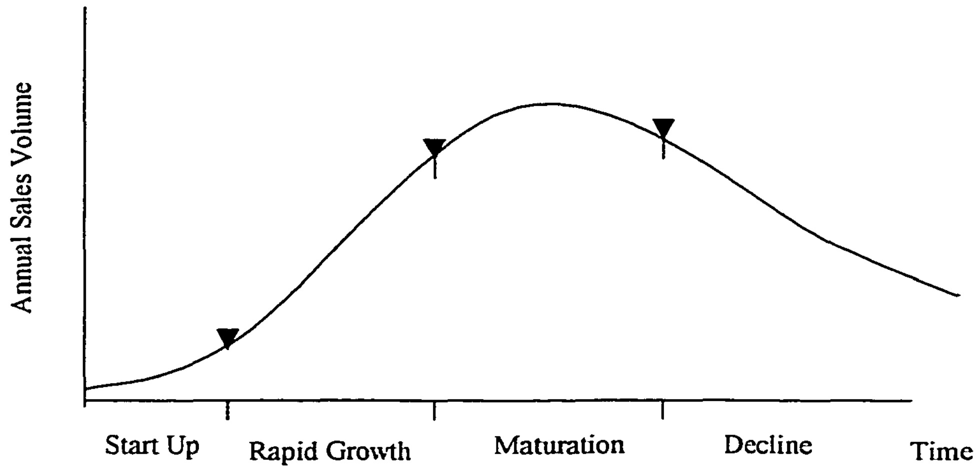
In this paper, we define an "R&D community" as a group of individuals and groups or organizations who are committed to solving a set of inter-related scientific and technological problems by communicating with each other through a variety of methods (i.e., papers in academic journals, papers in conferences, patents, and e-mail), regardless of language, culture, organizations or geographic location.

This section reviews theories and concepts that are related to our study on the R&D community. Each theory or concept is reviewed separately in this section.

3.1 Product Life Cycle Model

A product passes through a number of phases: start-up, rapid growth, maturation, and decline. Figure 2 illustrates a product life cycle model. The introduction starts from a market niche. The rate of product penetration is very slow, since the product is new to the market. When the product is acceptable to many customers, growth occurs in this period. Profits from the product start in this phase but the rapid growth eventually stops when the penetration of the product to all potential customers is reached. Profits stabilize in this phase and the growth of the product declines as new substitute products appear.

The product life cycle model is an important concept although there is criticism that the model does not describe real observations (Porter 1980). However, the model helps us understand the nature of products in general. A company has to overcome the buyer's inertia so that the product can penetrate and diffuse into the market in the introduction phase. In a competitive environment, the company must be continuously aware of the entry of competitors.



Source: Modified from Hayes, Robert H. and Wheelright, Steven C., "Matching process technology with product/market requirements." In Reading in the Management of Innovation. Ed. by Michael L. Tushman and William L. Moore, Ballinger Publishing Co., 1988, p.422.

Figure 2: Product Life Cycle Model

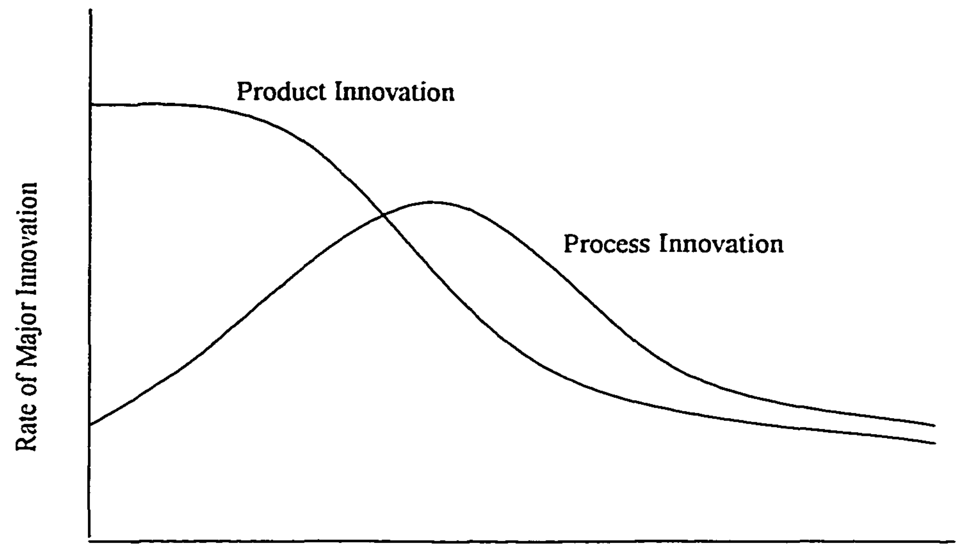
This theory can be applied to the R&D community. In the beginning of a new area of technology, knowledge is lacking and unclear. Only a few researchers are interested in this area. Therefore, few papers are published during this first period of time. Once the researchers find new interesting ideas, other researchers will join in the R&D community, and the amount of literature increases rapidly. When the knowledge becomes clear and reaches its limitation of applications, the amount of literature remains constant for a while, then declines as time passes.

3.2 The Dynamics Model of Innovation

The phenomenon of industrial product improvements directly threatened by a new technology is a common pattern. Utterback and Abernathy (1978) and Utterback (1994) propose the dynamics of an innovation model. This model is based on historical studies of innovations. The model has three phases and explains the pace of innovation over a period of time. There are two innovations in this model: (1) product innovation and (2) process innovation. The vertical axis shows product and process innovation rates in each phase. The horizontal axis shows the period of time.

This model relates to the product life cycle model. Figure 3 illustrates the dynamic model of innovation. Initially, the product is developed from ideas. Firms have to focus and develop a product from a stream of ideas. This phase is called a "fluid phase." The product is changed frequently and its market is unknown. Firms must use more effort in this phase. Therefore, researchers have to work hard to define what the product should be and what customers need. In this phase, the product innovation rate is high, whereas, the rate of process innovation is low.

When the major product designs and operations are specified, the rate of product innovation declines but the rate of process innovation increases. This period is called a "transitional phase." The firms begin to analyze processes on the factory floor. In this phase, the product and process innovations link more closely with each other. Scientists and engineers begin to think about how they can produce the product efficiently and effectively.



Source: William J. Abernathy and James M. Utterback, "Innovation Over Time and in Historical Context." In Reading in the Management of Innovation. Ed. by Michael L. Tushman & William L. Moore, 2nd ed., Ballinger Publishing Company, 1988, p.27.

Figure 3: The Dynamics of Innovation

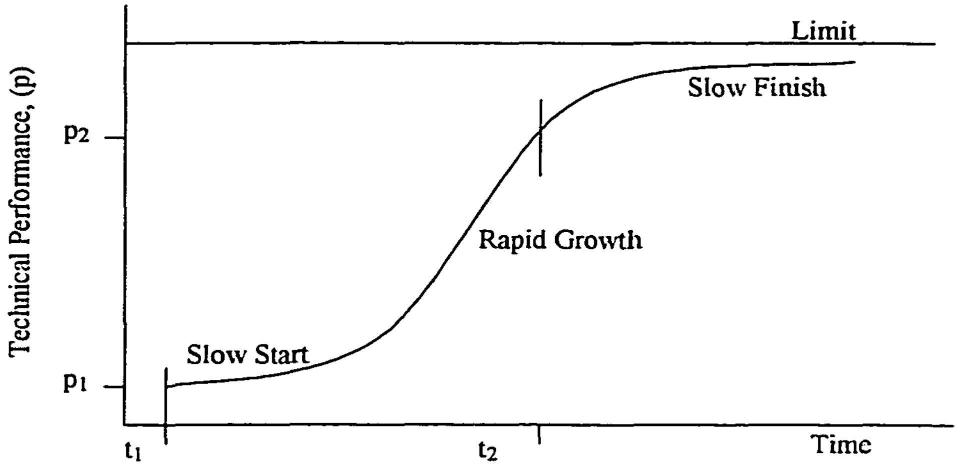
Once the product is launched into the market, firms should keep improving their products with both product and process innovations. They will begin to considering more specific areas such as how to reduce their production costs, how to improve the product quality, etc. This period is called a "specific phase." The rate of both product and process innovations stabilize at a low level.

The dynamics model of innovation theory can also be applied to the R&D community. Researchers think of new ideas in an area of technology. The necessary knowledge and possible problems are not yet evident. For instance, their ideas are called an *idea product* and their experiments are called *experiment products*. This stage is the same as the "fluid stage" in theory. Additionally, there are few researchers in the early stage. In the "fluid stage," researchers emphasize their ideas more than their experiments. Therefore, the rate of idea products is higher than the rate of experimental products.

After they gain confidence in the new knowledge, some researchers try to create their experiments. The idea will transfer to the experiment. Many researchers are convinced of the new knowledge by interesting results or ideas. This is the same as the "transitional stage" in the theory. The rate of idea products decline and the rate of experimental products increase. When the "specific stage" is reached, there are some ideas and experiment products in the R&D community. However, the number of ideas and experiments is limited. Furthermore, the ideas and experiments are extremely specific.

3.3 The S-Shaped Curve Theory

There is a theory that explains an overall perspective viewpoint of technology performance from an emerging stage until it disappears or is replaced by another technology. It is called the S-shaped curve or growth curve theory. The growth curve represents a loose analogy between the growth in performance of technology and the growth of a living organism (Martino, 1993).



Source: Modified from Foster, Richard N., "Timing Technological Transitions." In Reading in the Management of Innovation. Ed. by Michael L. Tushman & William L. Moore, 2nd ed., Ballinger Publishing Company, 1988, p.217.

Figure 4: The S-Shaped Curve

Technical performance, which is the vertical axis of the graph, is a composite indicator for two characteristics. It represents both technical characteristics - measured by any kind of physical measurement: size, power, weight, speed, etc., and economic characteristics - measured by the market price utilization cost (Metcafe and Saviotti, 1984; Saviotti, 1988). S-shaped curves are used to forecast a given technology as it approaches its upper limit (Martino 1993).

Figure 4 illustrates the S-Shaped curve. In Figure 4, the curve expresses the idea that the progress of technological performance tends to flatten out after development. At period t_1, a technology emerges at the technological performance level p_1. During the period t_1 to t_2, the technology development increases at a high rate until it reaches period t_2. At this point, the technical performance starts to slow down. At t_2 stage, the technology almost reaches its ultimate performance by the laws of nature (Foster, 1986).

The laws establish the maximum performance that can be obtained using a given principle of operation.

This theory is concerned with the study of the R&D community by considering the researchers' knowledge of how to solve a problem in a specific field. In the beginning, it is quite difficult to know what knowledge to use and how to apply it to solve the problem. He/she may not have enough knowledge and the problem may be a new one. Once the problem is defined, one studies and becomes acquainted with the problem. At this stage, one's knowledge about the topic accumulates rapidly. Finally, one can solve the problem by using specific knowledge and technology.

After solving the problem with knowledge, he/she can apply or modify that knowledge to solve other problems. At this time, researcher performance levels are high. However, the same knowledge cannot be employed to all problems. New problems require new knowledge to solve. Thus, a person's former (old) knowledge has limited applications to the newer problems.

3.4 Substitution Curves

Technological maturity does not imply that innovation has come to the end (Moenaert, Barbe, and Deschoolmeester, 1990). We consider this concept at the level of the strategic business unit, not at the level of industry. Firms have to find new methods to solve new problems. Clark (1983) proposes three possible ways to reversal maturity: (1) changes in demand preferences, (2) supply-side change in technology, and

(3) changes in prices of substitute or complementary products. If a business unit can "jump" to a new set of promising technologies, it will begin another S-shape growth curve.

Adoption of a device using a different principle of operation and/or a different material means a transfer to a new curve. Frequently, one who is interested in the pace of a given technology will find that a new technology can be substituted for the old technology. Figure 5 illustrates substitution curves. Initially, an old technology (Technology A) has many advantages such as its performance, reliability, and services whereas, a new technology (Technology B) is unknown and its performance and reliability are uncertain. Therefore, the substitution rate of the new technology during this period is slow.

When the problems are solved, the substitution rate increases. The new technology (Technology B) becomes a well-known technology. Many advantages are developed while the old technology (Technology A) becomes obsolete. There will, however, remain a few applications for the old technology for development by a few individuals or organizations in specific areas.

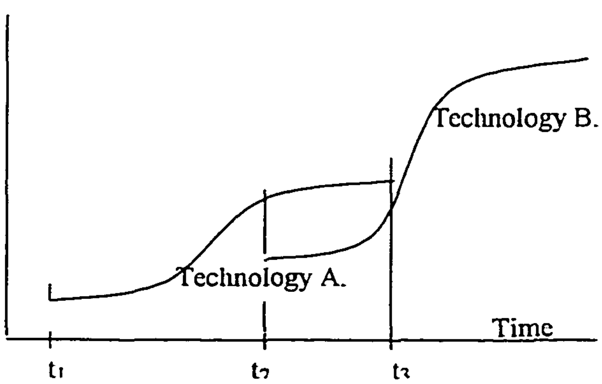


Figure 5: Substitution Curves

The substitution curve often exhibits a growth curve as well. The technical performance of each technical approach is plotted on the same graph. Generally, there are technical "discontinuities" in the graph. In Figure 5, there are two technologies (Technology A and B) during the period t_2 to t_3. Substitution curves are frequently used to forecast the substitution of one technology for another technical approach.

This theory can be employed in this study. When a researcher cannot use his/her old knowledge to tackle a new problem, he/she has to study and accumulate new knowledge. When, again, the new problem is defined and new knowledge is accumulated, then he/she can solve the problem. This creates a new S-shaped curve that is higher on the performance scale than the old one. It means that one's knowledge is increased from the past. As long as the researcher maintains an interest in this field, he/she will gain new ideas and solve new problems. Of course, no knowledge is absolutely complete.

Researchers usually study and accumulate their knowledge. As we know, it is difficult to find and study a new knowledge from general classes in academic institutions. Communication among researchers is an effective way to acquire new knowledge. Therefore, networking is an important tool to obtain knowledge efficiently. If a researcher does not network, he or she probably will get new knowledge later than others.

3.5 Compatibility and Standardization

Compatibility is an important issue in industrial economies because most products consist of many parts. The use of interchangeable parts must be considered. Products must meet certain standards to be compatible. There are four benefits of compatibility:

(1) network externalities, (2) competitive effects, (3) variety or mix-and-match benefits, and (4) cost savings (Farrell and Saloner, 1986).

Products can be linked together through their physical or conceptual compatibility. An obvious example is computer networks that are linked together by using both hardware and software products. When competing products are compatible, they will compete with each other based on price rather than on design.

While compatibility limits a variety of designs, it increases the available variety of mix-and-match purchases. For example, the buyer of a computer system can combine any CPU, monitor and/or printer since these products have compatibility. Thus, manufacturers can produce the products in large volumes with reduced production costs. Another cost saving benefit of compatibility is that it also saves on learning costs. Users do not have to spend their time and money to learn how to use the products.

To standardize goods, manufacturers have to set standards. In competitive markets, especially for complementary goods, standards play an important role[2]. Standards can lengthen the economic life of products based on larger markets, and therefore, customers will have more choices to buy goods and they will usually prefer to buy better ones. Since the products have many components, the quality of the components affects the performance of the goods. Quality also affects the performance of firms. Thus, firms have to determine which components to make or buy to ensure the necessary level of quality.

Standards can reduce the uncertainty of goods performance. If components provided by others meet the standards and the acceptable level of quality, they will work properly. Because multiple standards exist, suppliers or manufacturers have to determine which standards the customers or end-users need or use and try to produce their goods and services to meet these standards. From this viewpoint, standards facilitate competition between firms that use different standards.

Some large firms have developed their technologies for a long time, and therefore, set their own technological standards. Generally, firms that are located in different locations have different standards. In the past, firms had to manufacture all components by themselves. With highly competitive markets, firms must decide which components they will outsource. Firms and their trading partners have to determine and use the same standards now more than in the past.

The stability of the standard is not guaranteed. Standards may create uncertainty in competition. Some firms may have greater control than others over standards, thus, they are able to determine what standards should be and when standards will change. However, large firms do not necessarily have more power than small firms. In many standard industries, network externalities is an important factor (Krickx, 1995).

When standards and network externalities are present, customers prefer to accept, install, and use the standards widely. Common standards, open standards, and liberal licensing lead to a larger number of users of new technology. This means that goods can be produced in mass quantities and cost less at the same performance level. Farrell and Saloner (1985, 1986) state that the ability to interchange complementary products may be greater than in the past with dominant standards.

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[2] Complementary goods are individual goods which when put together form composite goods. For example, a PC should have a monitor and a CPU.

In fact, the dominant system firm tries to defend its position by improving its product performances and making it difficult for others to adopt the standards (Delamarter, 1986). When its owner promotes one technology as a standard, then that technology is likely to win over other unpromoted technologies (Katz and Shapiro, 1986). But in some industries, when dominant firms change standards, they may lose some control over their installed base because they are constrained in their product offerings (Krickx, 1995).

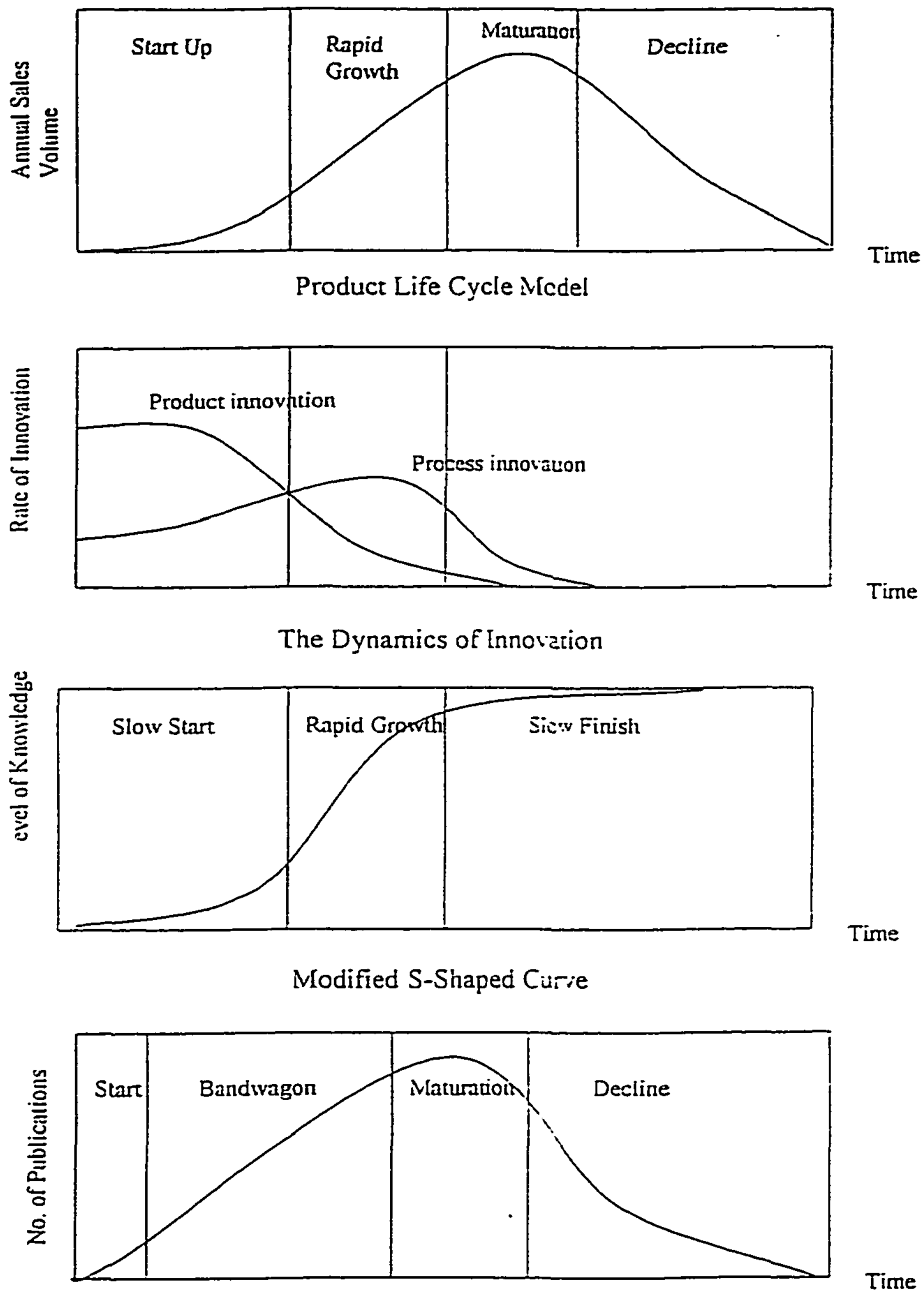
The compatibility and standardization concept can be applied to this study. When new knowledge is interesting, many researchers and/or organizations are interested in the new knowledge. The more they study, the clearer the new knowledge becomes. Researchers need to know what others did and did not study, as well as the standards and methods used in the experiments. This phenomenon reduces the uncertainty about the new knowledge in the R&D community. Furthermore, if the new knowledge is useful and compatible, researchers benefit from the new knowledge rapidly. The amount of literature in R&D communities about this technology will increase.

4. R&D Community Model

The R&D community model observes the number of literature papers produced by researchers as a gauge of activity in a community. In the beginning, the productivity of researchers is very low because there is a small amount of researchers who are interested in a specific field. Most researchers do basic research. Although the productivity is slow, basic knowledge of the R&D community gradually accumulates.

The researchers communicate frequently. They compete and collaborate with each other at the same time. Researchers' knowledge increases and their productivity also increases. Since applications or products of the technology are interesting, researchers continue to conduct their research. Researchers' knowledge increases as long as they conduct research. When many researchers become interested in the R&D community, then the amount of literature increases rapidly. During this period, the amount of application research increases, whereas, the amount of basic research decreases.

When applications or products of the technology are not interesting anymore, researchers look for other interesting technologies. The amount of literature reaches its maximum at some point and then starts to diminish. Though, the amount of both application and basic research decline, the knowledge of the R&D community does not decline.



Source: Modified from Yamada, Hajime, "The Emergence of A New Technology: The case of Semiconductor Laser Diodes", Master thesis in the Management of Technology, Sloan School of Management, MIT, 1990, p.37.

Figure 6: An R&D Community Model

5. The Importance of Persistence

The R&D community can sometimes be considered as an "invisible college," where researchers can exit from the R&D community at anytime. In the R&D community, each member helps other members indirectly at the macro level. It is good for researchers to persist because they continue to receive new knowledge. Any type of knowledge such as general ideas, proposed models, or results of experiments are important knowledge to other researchers. We can determine the amount of knowledge in an R&D community through the number of members within the community. The more researchers, the greater amount of knowledge that is contributed to the community.

In the micro level, organizations can take advantage of the R&D community, thereby, reducing technological uncertainty and avoiding some mistakes. Researchers can accumulate a variety of scientific and technological knowledge through the R&D community. Thus, they can manage and conduct R&D effectively and efficiently.

In order to understand the R&D community effectively, we have to study researchers' behaviors in the community. An amount of time (i.e., a year) that a researcher contributes his or her knowledge to the R&D community relates to his or her accumulation of knowledge. A persistence behavior is selected. This dissertation focuses on the persistence of researchers, organizations, and nations because we believe that it enormously affects the level of innovations.

One may have a question about persistence of an organization which may not relate directly to organizational performance. It is possible that some organizations may achieve great innovations within a short period of time. They can take advantage of these for years. However, their competitors will soon make their innovations obsolete if they do not continue to develop their technologies. Therefore, persistence of an organization or nation still relates to its performance and modifications and keeping abreast of other researchers work in the R&D community.

CHAPTER III

THEORETICAL FRAMEWORK

1. Introduction

Innovation management is complex, although its objective is simply stated to keep innovation on-going effectively. Unfortunately, there are conflicts between researcher's autonomy and organization's goals. These conflicts affect researchers' efficiency and organizational performance. Management needs understand and obtain answers to questions such, why do researchers pursue the lines of research they do? What are influential factors that affect the persistence of researchers in their research (at an individual level)? Additionally, management also needs to know the answer to the question, what influential factors affect organizational persistence in a given technology (at an organizational level)?

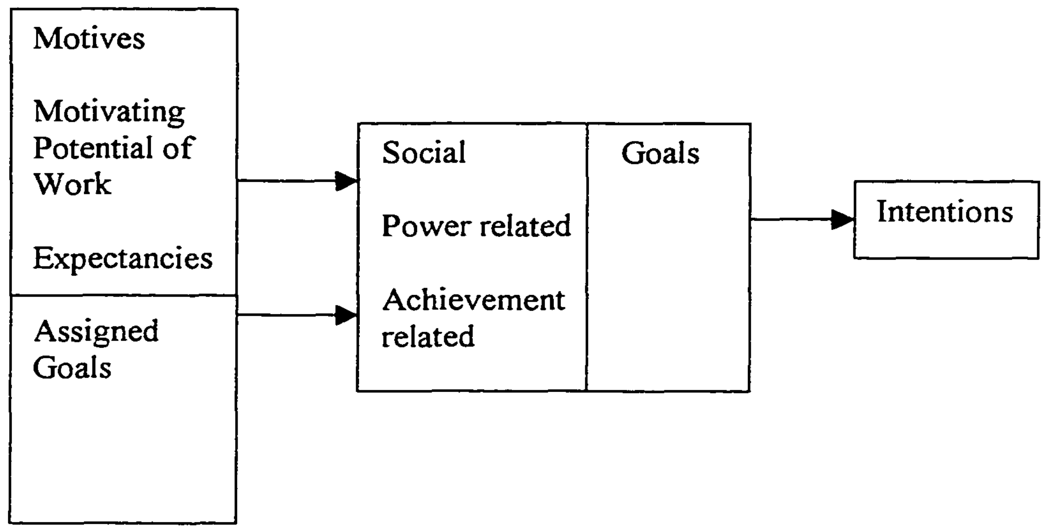
Technological innovation concerns a number of identifiable macro and micro level discriminators (Dunphy, Herbig and Howes, 1996). They define macro level as the national level and micro level as industry and firm levels. This dissertation defines macro level as a country level and micro level as an individual and organizational levels. In order to study these problems, we will separately discuss the persistence of researchers at an individual level and the persistence of organizations at an organizational level in a given technology.

2. Review on Motivation Theories

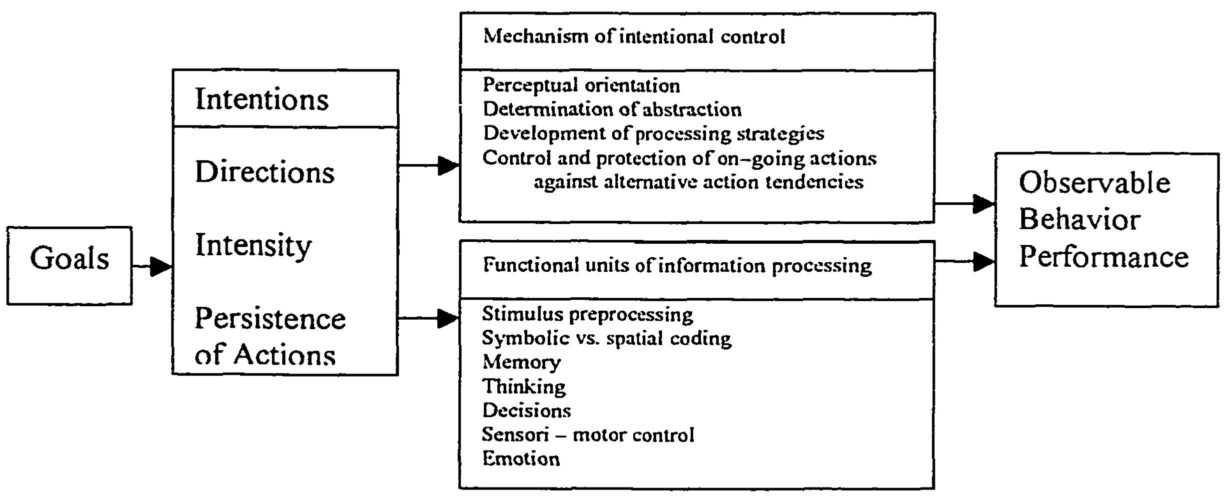
Sociological studies of scientific and technological communities have contributed a great deal to our understanding of the research and development processes. A common approach is to distinguish between factors that influence individuals or organizations' decisions, especially whether they are internal and external factors (Stehr and Ericson, 1992; Stewart, 1990). The internal factors are the cognitive and the social needs. Researchers use their judgement to determine problems that are interesting and tractable under the state of current knowledge and technique (Rappa and Debeckere, 1995).

Kleinbeck and Schmidt (1990) propose a framework about the process of translating motivation into actions (Figure 7). They show a relationship between motives, goals, intentions and observable behavior performance. The persistence of actions is in an "intentions" block. This means that persistence of actions is required in order to get the final outcome (the observable behavior performance).

The framework is not appropriate enough to explain the influential factors affecting the persistence of individuals or organizations in the R&D community. Because it sometimes lacks feedback from other people or themselves, it is a one-way process. Satisfaction of individuals or organizations may affect the persistence. Based on the R&D concept, nothing is completed. Researchers have to develop innovative works.



A. Motivation Process



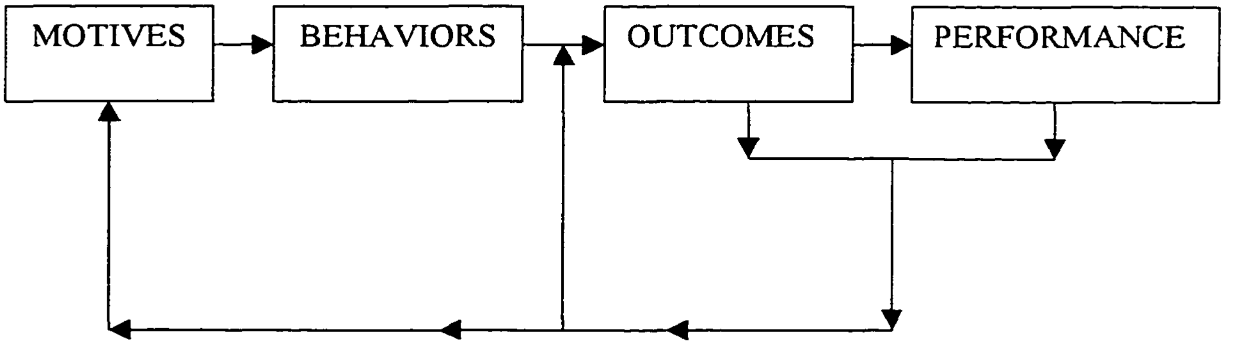
B. Volitional Process

Source: Kleinbeck, Uwe and Schmidt, Klaus-Helmut, "The Translation of Work Motivation into Performance." In Work Motivation. Ed. by Uwe Kleinbeck, et al., Lawrence Erlbaum Associates, Publishers, 1990, p.28.

Figure 7: A process of translating motivation into actions

Thierry (1990) presents a cycle of motivation (briefly summarized). The motivation cycle is illustrated in Figure 8. Although this model is very brief, it illustrates a basic relationship between motive, behavior, outcome and satisfaction. It is a two-way relationship. Since the final outcome is done, some degree of satisfaction is archived. Furthermore, the degree of satisfaction affects the motives and behaviors.

As an example, we may consider a person sets his/her goal to make money, e.g., $1M in one year. However, after one year, only $0.8M is made. Will he/she be satisfied with his/her performance? The answer may be yes/ may be no. If satisfied, then some factors affecting one's performance (e.g., economic crisis and high competitive environment) cannot be controlled. If one is not satisfied, then he/she may have to change their behaviors in order to achieve the original goal.



Source: Thierry, Henk, "Intrinsic Motivation Reconsidered." In Work Motivation. Ed. by Uwe Kleinbeck, et al., Lawrence Erlbaum Associates, Publishers, 1990, p.28.

Figure 8: Cycle of Motivation (briefly summarized)

This example refers to two factors that affect the degree of satisfaction: (1) the external factor (economic crisis and high competitive environment) and (2) the internal factor (his/her commitment, culture, norm, and values). Based on the literature survey, we have developed a cycle of a motivation model which will be discussed in the next topic section.

3. Basic Framework

Generally, individuals or organizations start their careers or work by their intrinsic motivation and/or extrinsic or "external" motivation[1]. Intrinsic motivation is considered as being positive, good, and constructive. On the other hand, extrinsic motivation is considered to be negative. It shows something is lacking, depleted, and/or eventually runs out such as financial support, laws, competitive environment and time.

Once individuals or organizations have their motivation, they determine their goals. Generally, the goals are based on their capabilities and/or expectancies by either management or by themselves or both. Sometimes, it is possible that the individual goals are also their organizations' assigned goals. When determining and setting goals, they have to consider a set of internal factors such as their capabilities, norms, and culture. They should also consider a set of external factors such as social culture, competitors, and/or laws.

Most works have limited resources, such as financial budgets, equipment, and time. Once individuals or organizations invest, they need to get results. Their investment may succeed or fail. How do they know whether their investment is successful? They

[1] Thierry (1990) defines "intrinsic motivation" as something from within from the inner part of the person that is causing the specific behavior.

have already set criteria to evaluate whether their investment will be a success. Thus, it is necessary that goals are measurable. Individuals or organizations must be able to evaluate their performance through measurable goals.

Generally, goals are considered as a destination. There are many directions or paths to reach the destination. To achieve their goals, they have to determine their direction and devote their efforts to achieving their goals. This process takes time, energy, and other resources. During this period of time, the internal and external factors also affect this stage. Serious external factors (e.g., economic crisis and natural disaster) may affect this stage. Furthermore, individuals and organizations may set short-term and long-term goals. Nevertheless, individuals or organizations have to persist in their works to accomplish their goals, whether short term or long term.

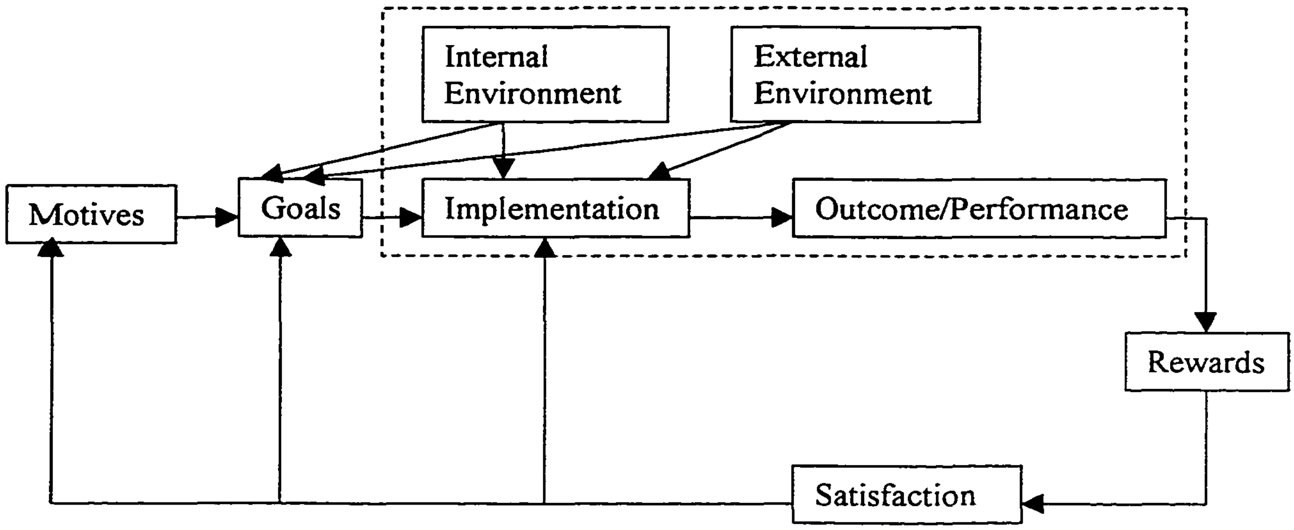
The output of individuals' or organizations' efforts is their performance. According to the information processing in science and technology shown in Figure 1 earlier, products of technology system are physically encoded information (hardware and other products) and verbally encoded information (documentation). These products are the performance of scientists and engineers in the scientific and technology system, as will be shown in Figure 9.

Most of the hardware and other products are sold to a market. The products are evaluated by both technology experts and final users. Eventually, the final users determine whether they will buy this product. Documents (papers and patents) are published and contributed to the R&D community. The documents also are evaluated by experts and additional researchers in the same R&D community. Some literature is awarded and/or recognized.

Basically, successful products are measured by using market shares and total sales. A large market share and a large amount of money are successful indicators for an organization from its business. On the other hand, awards of academic journals or institutions can be a good reward for documents. Consequently, this positive output enhances organizations and their researchers to keep doing the work until they reach their goals.

Sometimes their performance does not go through a "reward" stage because the overall performance does not live up to the goals and expectations they sought. Not all inventions are patented and become innovations. Only some literature achieves awards. The output is negative and/or mixed with positive and negative output. Ambiguity of the final output occurs. However, since the work is done, individuals or organizations are still able to achieve some degree of satisfaction.

Organizations/researchers receive feedback from many sources to evaluate their performance and use this information for their future work. Degrees of satisfaction depend on a variety of factors such as feedback, expectations, performance, and environment. The level of their satisfaction affects their motivation, goals, behavior and performance in their future works. Figure 9 shows the cycle of a motivation model.



Note: [dashed box]: The Dissertation Framework

Figure 9: Cycle of a Motivation Model

However, this dissertation focuses only on some elements of the cycle in the motivation model because of limitations of the bibliographical database. There is no data available to measure motives, goals, satisfaction, or rewards elements. Therefore, the study focuses on internal environment, external environment, implementation, and outcome/performance elements.

4. Individual Persistence Framework

This section discusses six theoretical perspectives contributing to the study of the persistence of researchers in an R&D community. The study integrates relevant theoretical concepts from technological network approach, reputation or reward approach (Badawy, 1988; Manners, et al., 1988), research diversity approach, sunk cost approach and technological characteristic approach. The interested factors which may affect persistence will be described.

The *sunk cost approach* describes when once an individual or organization has invested time and money in one research area, they are less likely to switch to other areas. The *technological network approach* explains that an individual needs other people to provide, advice, help, or to work as a team. According to the complexity of their work, an individual cannot accomplish the job alone. The *experimental work approach* explains that researchers who conduct research in laboratories may contribute their knowledge to an R&D community longer than others. The *research diversity*, defined as researchers who conduct research in many disciplines, should facilitate greater persistence in the R&D community. The *technological characteristic approach* explains that each technology has its own set of characteristics. Some technologies need more time and more financial support to develop. The *reputation/rewards approach* explains an individual needs recognition from other people. In a highly competitive society, achieving a basic level of recognition is not enough. An individual needs a higher level of recognition, i.e. a good reputation among peers, colleagues, and many others. This leads to persistence for this person's research to continue. Figure 10 illustrates an individual's persistence framework.

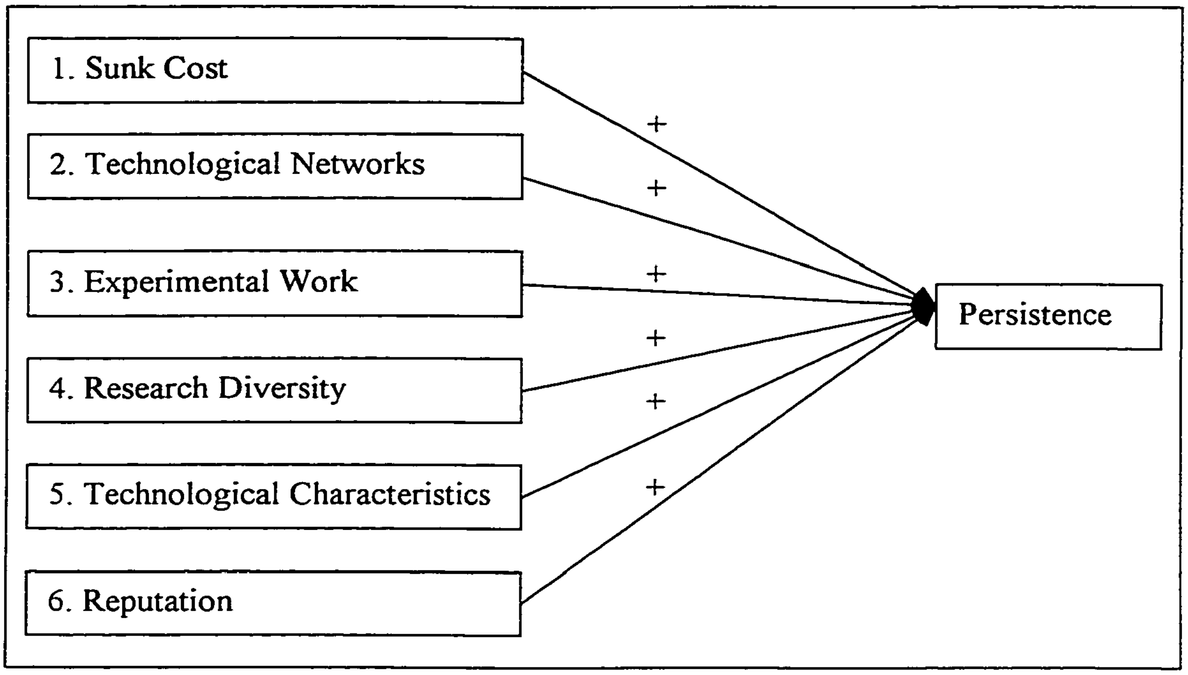


Figure 10: An Individual Persistence Framework

4.1 The Sunk Cost Approach

The term "sunk cost" is defined as resources which invest in the past before any or all of the benefit arise, and then an investor does not take the value of resources as a cost into their today's decision-making. The "sunk cost" theory is employed in the decision-making process. Theoretically, investors do not consider their "past investment." Practically, sometimes, it is difficult to follow that theory. Generally, management is entrapped in their decision making.

Researchers have been studying in a specific field for many years. They invest their time, energy and any resources to gain knowledge. It is difficult for them to start all over studying in a new field of knowledge, or to quit the old established field. They have to keep going forward in their fields of knowledge. The more scientists and engineers contribute their knowledge, the more they invest in their knowledge. Thus, we believe that researchers who publish a greater amount of literature tend to persist in their old areas of knowledge.

4.2 The Technological Network Approach

Basically, researchers accumulate their knowledge through a variety of methods (e.g., studying, experimenting) individually. Unfortunately, there are individual limitations such as time, financial support, and knowledge. Additionally, today's scientific and technological knowledge is complicated. Researchers need to have a variety of resources to overcome their problems effectively, therefore, they collaborate with other researchers. With this methodology, they can also take advantage of each others knowledge.

Furthermore, group behavior enhances their members' behaviors. Lamm and Myers (1978) state that individuals desire to be socially acceptable. The "social comparison view" is considered. Some individuals whose performances are below the group average become aware of their relative position through group interaction. Thus, they move toward the more socially favored positions.

Generally, researchers work with other researchers who either work in the same organization or other organizations. In this way, a researcher has his *technological network*. The amount of researchers who work with a researcher is considered as a technological network. We believe that the greater amount of a researcher's technological network will be positive to the persistence of the researcher in the R&D community.

4.3 The Experimental Approach

Based on the innovation concept, researchers have to accumulate knowledge continuously. Furthermore, tacit knowledge is very difficult to achieve, and is best achieved through experiences. Therefore, they have to study and experiment by themselves. This "tacit stage" enhances the researchers to be experts in specific fields. Because of the time consuming process, the "tacit stage" also limits their knowledge in other fields.

Since tacit knowledge can be archived only through experience, researchers who propose theoretical literature or other types of literature to the R&D community can gain tacit knowledge because they have studied by themselves. While this is true, there are some things to consider about experimental literature.

Basically, when a researcher conducts an experiment, there are some controlled variables. As an example, we may consider a running test of an athlete. Some variables are controlled such as wind velocity, weather conditions, and distance. If these variables are not controlled, the athlete's performance may vary. Some complicated experiments may have a variety of variables to control. Researchers may separate a big experiment into smaller experiments. Therefore, they can contribute their knowledge many times.

We may consider other types of literature (theoretical, general review, new development and practical). Generally, they are contributed in a completed literature. Additionally, researchers have to set equipment for their experiments. Once the equipment is set, they need to use it for awhile. The greater amount of investment, the greater commitment to conduct experiments they have. We believe that the greater number of experimental papers a researcher publishes, the longer his persistence.

4.4 The Research Diversity Approach

Based on the "create destruction" conceptualization (or Schumpeter Mark I model) of technological change, innovation process is an uneven and random process (Malerba, et al., 1997). Innovation generates monopoly power only for a temporary period. It is challenged by innovative success of competitors in the following period. Additionally, the competitors may pounce quickly since the relevant knowledge base is easily accessible.

Another conceptualization of technological change process is the "creative accumulation" concept (or Shumpeter Mark II model) (Malerba, et al., 1997). This concept describes that technical knowledge has a strong tacit component and offers a high specific knowledge to individual organizations and applications. Over time, the specific, tacit, and cumulative nature of knowledge of the organizations builds higher barriers to enter. It is very difficult for new innovators to dominate the market in a stable oligopoly.

Based on both conceptualizations of technological change, Malerba, et al. (1997) state that disruption of the leading technology requires drastic changes in the relevant technological paradigm. To achieve the relevant technological paradigm, researchers have to accumulate a variety of knowledge. Diversity in perspectives can help reduce uncertainty and resolve ambiguity (Daft and Lengel, 1986).

A variety of scientific and technological knowledge enhances innovative opportunity. Thus, a variety of scientific and technological knowledge may affect the persistence in the R&D community. We have focused on a variety of areas of technology that contribute to the R&D community and whether it may affect the persistence of researchers.

4.5 The Technological Characteristic Approach

Basically, technology has its own characteristics. For example, a semiconductor technology is a material based technology. Although researchers increase the capability of a semiconductor through process improvement, when it reaches the ultimate capability of material, the maximum capability of the semiconductor is also reached. The researchers have to study how to discover new materials that have better properties than the old materials.

Generally, material technology is a high investment technology and is a long-term investment. Management expects to reap benefits in the long term. Scientists and engineers also have a long-term commitment with the investment. Therefore, our proposition is the more published papers that are related to material a researcher publishes, the longer his persistence.

4.6 The Reputation Approach

The self-perception theory is employed. There are three aspects that incorporate this theory, including traits, competencies and values. First, traits are labels for a variety of reactions, tendencies, as well as expressing relatively permanent patterns of behavior

(Cattell, 1965). Secondly, competencies are individual perceptions of skills, abilities, talent, and knowledge. Thirdly, values are the beliefs about desirable ends that transcend specific situations, guide selections, or are evaluations of behaviors and events (Schwartz and Bilsky, 1990).

The "social comparison view" is also given consideration. Individuals usually evaluate themselves by comparing themselves to others (e.g., their intelligence level relative to others) or with a fixed standard (e.g., to earn a bachelor degree). Self-perceptions are determined through interaction with one's environment. Individuals with strong self-perceptions are relatively firm in their actions and reactions. On the other hand, individuals with weak self-perceptions are relatively not firm in their actions and reactions (Leonard, Beauvais, and Scholl, 1995).

Social identification is defined as individuals who classify themselves and others into different social categories (e.g., man and researcher). The social identification has a set role for expectations and the norm which guides the individual's responsibility. Responsibility has been suggested to be a critical factor in individual persistence (Staw, 1976). Individuals see themselves differently in each of their roles (Roberts and Donahue, 1994).

Once individuals develop self-perception, responsibility, and a social comparison view, they can evaluate themselves through their task and social feedback. Task feedback can be observed directly from their tasks. Social feedback is difficult to measure directly. It depends on the individuals' traits, competencies, and values. Generally, experts usually get both task and social feedback highly due to their expertise, e.g., instructor versus full professor in a university.

We notice that some journals attach researchers' bibliography with their papers. Most bibliographies provide backgrounds such as date graduated, university degree received from, positions and responsibilities, articles written, journals cited, and how many papers they have contributed to the specific field of technology. Furthermore, some journals show researchers' photographs.

Although all kinds of literature are presented with researchers' names, there is still a difference. In patent databases, people are hardly interested in inventors' names. A patent is used for commercial claims. Usually, the important point is who (the organization) is the owner of that technological knowledge. In a conference, although a speaker announces researchers' names before the presentation, the audience forgets them soon.

Journals are the most popular media. They are kept systematically whether in hard copy or electronically. Academic professors and graduate students always use journal literature in their references. Furthermore, some famous and highly regarded journals are very tight in their quality of literature. We believe that researchers who published their literature in journals also present their reputation. The greater amount of journal literature and the better the journal, the better their reputation. Consequently, we also believe that the greater amount of journal literature a researcher publishes, the greater persistence he tends to have.

5. Individual Hypotheses

According to the discussion on the factors influencing individual persistence, six hypotheses are developed as follows:

H1. The greater sunk cost a researcher invests, the greater persistence he tends to have.

H2. The greater technological networks a researcher works with, the greater persistence he tends to have.

H3. The greater number of experimental papers a researcher publishes, the greater persistence he tends to have.

H4. The greater research diversity a researcher publishes, the greater persistence he tends to have.

H5. The more published papers that are related to the technological characteristics of a researcher conducts, the greater persistence he tends to have.

H6. The greater reputation a researcher acquires, the greater persistence he tends to have.

6. Organizational Persistence Framework

This section discusses four theoretical perspectives contributing to the study of the persistence of organizations in an R&D community. The study integrates relevant theoretical concepts from organizational performance approach, technological strength approach, geographic location approach, and type of organization approach. Figure 11 illustrates an organizational persistence framework.

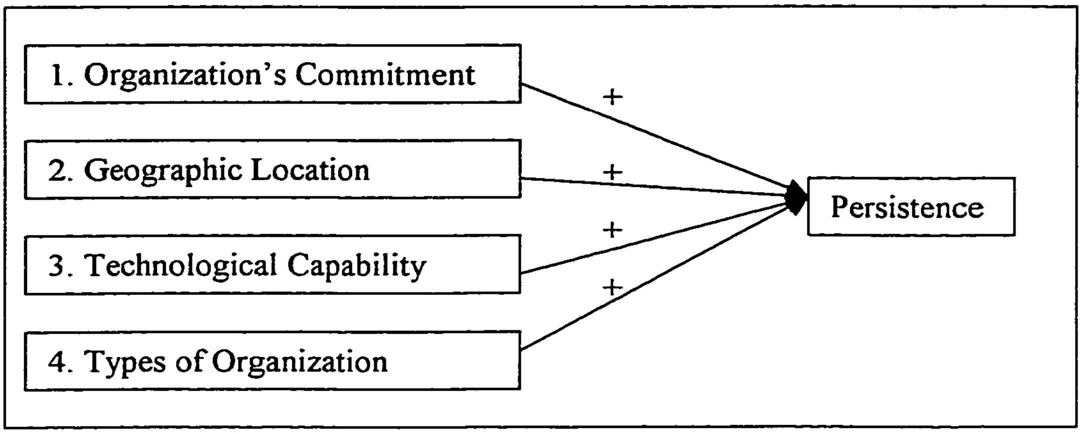


Figure 11: An Organizational Persistence Framework

The *organization's commitment approach* explores the total amount of literature of each organization affect to its commitment to the R&D community. The *geographical location approach* evaluates the effect of location to the persistence of an organization. The *technological strength approach* emphasizes the exploration and technological capability of an organization. Finally, the *organizational type approach* explains how the types of organization affect the persistence of an organization.

6.1 The Organization's Commitment Approach

Generally, organizations are different. Although they may have the same goals (e.g., to get the largest market share and to be a technology leader), they have different types and amounts of resources such as people, knowledge, and financial support. Therefore, their policies are different. Thus, researchers, who work in different organizations, are committed to their works differently.

In a highly competitive environment, organizations are also driven by their competitors. In order to survive in the competition, they must compete seriously. They may invest a great amount of money in both equipment and people and many projects may be planned and implemented. Some projects are long-term investments. Management is committed to these projects. Consequently, they need to get good results and survive the competition.

Since this dissertation focuses on the R&D community, we define organizational performance as a total amount of literature (paper and patents) of organizations that contribute to the R&D community. It does not refer to the amount of money, which an organization makes in a period of time.

According to the variety of degree of commitment in each organization, the performance of organizations also varies. The greater the amount of literature that is contributed, the greater degree of commitment an organization has. Therefore, we believe that the greater amount of literature that is contributed, the longer the organization's persistence.

6.2 The Geographical Location Approach

Generally, organizations tend to locate near their resources (e.g., raw material, and people) and markets. They can take many advantages such as reduced transportation costs, labor, number of customers, etc. In the globalization environment, firms may establish their companies in other countries for a variety of objectives. One interesting objective is to get scientific and technological knowledge, in addition to cheaper costs.

As we discussed earlier, tacit knowledge is difficult to achieve. It requires only experience. Some organizations take advantage by recruiting experienced people who may come from competing universities or organizations. Sometimes it is difficult for these people to move from their cities because they have their families and good facilities. Therefore, organizations may need to move instead.

The geographic location approach is developed based on many studies (Krugman, 1991; Teece, 1992; Almeida, 1996). Krugman (1991) states that a knowledge-intensive region relates to industrial firm clusters. Teece (1992) also supports Krugman's statement. He comments that the knowledge-intensive regions are attracted to foreign-based multinationals. Furthermore, once a foreign firm is located in that region, they contribute their knowledge back to the local technology progress (Ameida, 1996).

Based on the literature survey, organizations tend to locate in a good facility region. They are able to take advantage of the good facilities. Therefore, we believe that organizations that are located in a higher density knowledge region positively persist longer than other organizations that are located in lower density knowledge region.

In common language, density usually refers to the count for the geographic area (e.g., the number of persons per square mile). Hannan and Carroll (1992) define the density of an organizational population as the number of organizations it contains. We follow Hannan and Carroll's (1992) definition that the density of knowledge means the number of literature that is contributed by researchers who live in a specific area.

6.3 The Technological Ability Approach

Generally, organizations acquire scientific and technological knowledge through a variety of methods (e.g., licensing, reverse engineering). When their scientific and technological knowledge cannot stay any longer, it becomes obsolete. The organizations have to buy new technology. This acquiring strategy is not appropriate in highly competitive environments nor where technologies change rapidly.

Organizations have to develop their scientific and technological abilities. They may join research with other organizations, called technology alliance strategy, or develop their laboratories, called in-house R&D strategy. Researchers can develop tacit knowledge. This strategy enhances their scientific and technological skills. Consequently, organizations increase their scientific and technological capabilities.

Organizations tend to invest their time and energy in their core competencies. The term "core competencies" is defined as the collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple technologies, and the critical mass of competencies required to permit "delivery of value" (Prahalad and Hamel, 1990). If organizations have the strength of technological innovation, they will tend to persist in technological innovations.

Technological strength is measured through patents. A patent is a technological documentation that an organization registers and claims to be the first inventor and the owner. The greater amount of patents, the more technological strength an organization has. This means that scientists and engineers in that organization have a greater ability to create innovations. We believe that the greater amount of patents, the longer the persistence.

6.4 The Organizational Type Approach

It is known that organizations have their own characteristics and environment. For example, they are non-profit (e.g., universities and governmental laboratories) and profit organizations (e.g., firms). Management is different, therefore, the persistence of researchers in different types of organizations in the R&D community may be affected. Researchers who work in an appropriate environment (e.g., universities that allow researchers to conduct research in any area of R&D) are more likely to persist in the technology longer than others.

One may argue that researchers who work in good performance firms also tend to persist in a specific technology longer than the others. He/she may be right, but considering the conflicts between researcher autonomy and organizational goals, the firm researchers may have more pressure to switch to other technologies by force. On the other hand, university researchers usually can conduct their research as long as they are able to recieve financial support.

7. Organizational Hypotheses

Based on the literature that is discussed, four hypotheses are developed as follows:

H7. The larger amount of published papers and documents an organization contributes to the R&D community, the longer persistence it tends to have.

H8. If an organization is located in an area with a high density of knowledge, it will tend to persist longer than an organization located in an area with a lower density of knowledge.

H9. The greater the technological strength an organization has, the longer persistence it tends to have.

H10. Academic researchers are more likely to persist in the R&D community longer than other researchers.

8. National Persistence Framework

Differences in national values, culture, economic structures, institutions, and histories contribute to the competitive advantage of nations (Porter, 1990). This research explores some evidences that relate to the persistence of a nation in a given technology. We believe that differences in national values, cultures, technological prerequisites, histories, and economic structures may relate to national persistence in the R&D community.

This section discusses five theoretical perspectives that relate to national persistence in the R&D community. The study integrates relevant theoretical concepts from knowledge prerequisites, technological infrastructure, sociocultural tendencies, and knowledge diversity approaches. The hypotheses in this unit of analysis are also developed, based on the relevant theoretical concepts. Figure 12 illustrates a national persistence framework.

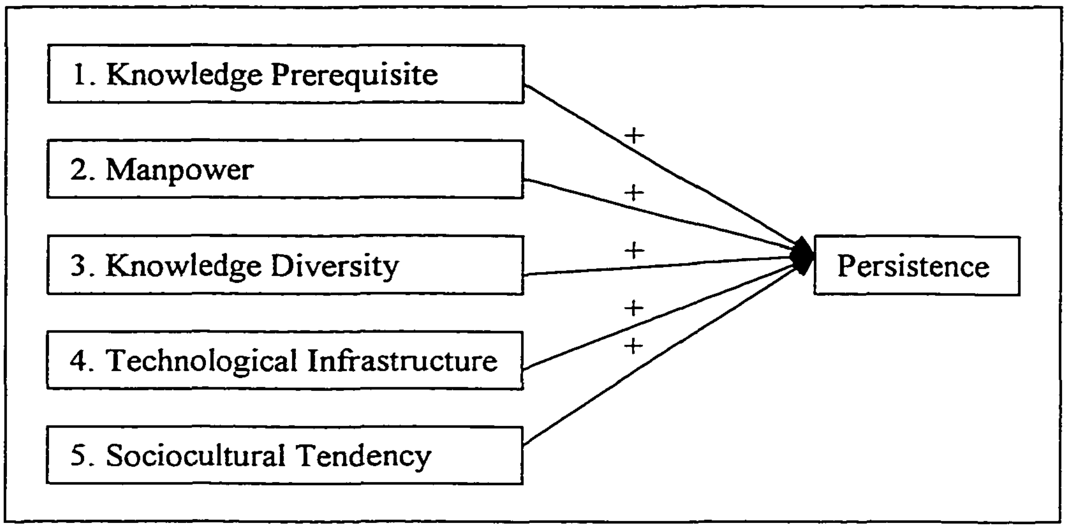


Figure 12: A National Persistence Framework

The *knowledge prerequisite* approach describes why a nation needs to have knowledge prerequisites. Although knowledge may spillover through a variety of literature, tacit knowledge is needed. The *manpower* approach explains how human resource is important to develop R&D at a country level. The *knowledge diversity approach* describes that more knowledge diversity should facilitate greater persistence in an R&D community. The *technological infrastructure* approach explains how the infrastructure affects the persistence of nations in an R&D community. The *sociocultural tendency* approach explains how different cultures (e.g., individualism and collectivism) affect the national persistence. Figure 12 illustrates a national persistence framework.

8.1 The Knowledge Prerequisite Approach

Based on the innovation concept, innovations are developed from the cumulating of scientific and technological knowledge (Padmore, Schuetze, and Gibson, 1998; Malerba, et al, 1997; Teece, 1996; Saviotti, 1995; Debackere, Clarysse, and Rappa, 1992;

Van de Ven, 1986; Ayres, 1986). Additionally, disruption of present technologies requires drastic changes in the relevant technological paradigm (Malerba, et al., 1997). In order to secure competitive advantage, nations need knowledge.

Generally, knowledge can be developed by a variety of methods such as licensing, reverse engineering, patent disclosures and publications, open technical meetings, etc. Achieving knowledge through these methodologies is easy and quick. However, there is at least one type of knowledge that is difficult to achieve. It is tacit knowledge. Learning by doing is an important complement for R&D (Nelson, 1996). Therefore, tacit knowledge is required.

Tacit, in other words, cannot be coded, it is embodied in a person, and cannot be reduced to merely a simply derivative. It is not easily applicable. It comes only with experience. The transfer of tacit knowledge may be slower and more expensive than the transfer of operating know-how (Scott-Kennis and Bell, 1988). An explicit example is developing countries sending their scholarship students to study in the US.

As discussed previously, knowledge and skill are important characteristics in technological change. Knowledge and skill are considered technological prerequisites (Dunphy, Herbig, and Howes, 1996). Consequently, we will consider the scientific and technological knowledge that is developed by individuals or organizations in a country in this approach. We believe that scientific and technological knowledge, developed in a country, represents some level of knowledge and skill of a nation in a given technology.

In a globalization environment, large enterprises establish their offices throughout the world. One question is how do we identify nation-based organizations in a country, e.g., a Japanese company, which is located in the United States. Almeida (1996) states that foreign firms use regional knowledge and contribute to local technological knowledge significantly, therefore, we consider that knowledge is developed in the United States.

Most governments support R&D projects both directly and indirectly. The government directly subsidizes R&D projects through university and government laboratories including human resource development. Sometimes governments support private firms' R&D by reducing their income taxes.

To get technological change, there are two stocks of resources: (1) the skills, knowledge, and institutions that make up a country's capacity to generate and manage change, and (2) the capital goods, knowledge, and labor skill required to produce industrial goods (Patel and Pavitt, 1997). They also state that to develop academic research capacities, support for postgraduate training, opportunities have made important contributions to technological accumulation. Therefore, a country that has a greater amount of knowledge will also have a greater opportunity to develop innovations. Based on this approach, it may persist in the R&D community much longer than those of other countries which have a lower amount of knowledge.

8.2 The Technological Infrastructure Approach

Porter (1990) states that a nation's competitiveness depends on the capacity to innovate and upgrade. Therefore, the government is expected to play an outstanding role to support and promote its innovations and upgrade them. Hilpert (1991) states that the government's roles are: (1) organizing academic research, (2) organizing markets for new science-based products, and (3) creating circumstances and providing the incentives appropriate for its innovations, e.g., regulation. For example, the research at MIT funded by the American Defense ministry, became a fundamental position in industrial markets (Hilpert, 1991).

Dunphy, Herbig, and Howes (1996) emphasize the relationship between the human infrastructure of a nation and its innovations. They state that "potential entrepreneurs need to be given the independence to initiate their ventures." They assert that a high level of venture capital available in the United States is the cause of a greater amount of innovations.

Based on the previous studies, the technological infrastructure can be human infrastructure, regulation, financial support, etc. This dissertation focuses on the number of organizations within a nation. We believe that the number of organizations within a nation represents the relationship among human infrastructure, regulation, and financial support. Organizations need technological infrastructure. Therefore, the greater number of organizations within a nation that contribute knowledge to the R&D community may persist longer than those of other nations.

8.3 The Knowledge Diversity Approach

As discussed in the research diversity in the individual level, the knowledge diversity is also an important issue in the national level. A nation's government is expected to support education and training. Researchers or organizations need to work in good environments (e.g., regulation, and pension) and facilities (e.g., communication system, libraries, and other infrastructures). They work legally on a variety of technological fields.

Disruption of the old technology requires drastic changes in the relevant technological paradigm (Malerba, et al., 1997). Hurley (1997) states that creativity consists of curiosity, motivation, persistence and knowledge. One may have some good ideas, but may not have the chance to conduct or test the ideas because of the lacking of good support. A government is considered as the facilitator or inhibitor of the research process.

A variety of technological fields show some degree of the facility of a nation. Researchers are supported by their government usually at some level. Consequently, we believe that the better the support on a research process, the greater amount of technological fields researchers conduct in a country. They should satisfy and persist in their work. Thus, we are led to a proposition designed to test a relationship between the total amount of technological fields and the persistence of nations.

8.4 The Manpower Approach

As we know, manpower is the most important resource in management. Developed countries have a variety of powerful knowledge and experts which enhance their economy, whereas, developing countries may lack these things. In highly competitive environments, firms compete with each other by offering higher salaries and better benefits to experts.

In our study, manpower refers to the number of researchers who study in a specific area of knowledge in a country. The amount of researchers in a country has some relationship with tangible and intangible values (e.g. their incomes and social status). Thus, we believe that the number of researchers may relate to their persistence in an R&D community.

8.5 The Sociocultural Tendency Approach

People have different values and cultures in different countries. Some cultures are more conservative than others. Ralston, et al. (1993) and Ricks, et al. (1990) state that a national culture drives values in the workplace. People who have different work values act differently from the others. Thus, the work values of different countries are focused in this approach.

Based on the Hofstede study (1980), he constructs contrast work values, which are individualism/collectivism construct in his study. He identified the United States as the country highest on individualism. Many scholars develop the Hofstede study's framework in their studies (Ralston et al., 1995; Holt, Ralston, and Terstra, 1994; Maccoby, 1990).

Ralston, et al. (1995) study the effects of the impact of work values in the United States, Russia, Japan, and China. Holt, Ralston, and Terstra (1994) find that individualism appears to equate to the Western culture, while collectivism appears to equate to the Eastern culture. Maccoby (1990) states that "the greater the freedom of the individual to explore and express his opinion, the greater the likelihood the individual will develop new ideas."

Most researchers work with their groups. Researchers' work values affect their work. In some cultures, junior researchers have to listen and obey senior researchers. Sometimes they come up with new ideas, yet they cannot express their ideas freely. If they do not like their work environment, they may quit. On the other hand, in some cultures, researchers feel free to express their ideas. With this environment, a variety of ideas are proposed. We believe that neither individuals nor organizations may persist longer in the R&D community than that of other work values.

9. National Hypotheses

We have developed five hypotheses regarding the national scenario in order for countries to achieve and maintain a greater persistence. They are as follow;

H11. The greater the knowledge prerequisites that are published by individuals or organizations in a country, the greater persistence the country tends to have.

H12. The greater amount of manpower that is contributed knowledge to an R&D community in a country, the greater persistence the country tends to have.

H13. The greater amount of knowledge diversity of a given technology that is contributed knowledge to an R&D community by individuals or organizations in a country, the greater persistence the country tends to have.

H14. The greater the technological infrastructure in a country, the greater persistence the country tends to have.

H15. The higher individualism work value of a country, the greater persistence the country tends to have.

CHAPTER IV

METHODOLOGY

1. The Output of an R&D Community

Since this dissertation focuses on an R&D community perspective, we will collect an R&D community's output or products. Based on an information processing in science and technology concept (Allen, 1988), there are three basic outputs: (1) verbally encoded information (papers), (2) physically encoded information (hardware and other products), and (3) verbally encoded information (documentation) as shown previously in Figure 1.

Verbally encoded information (papers), which come from the "science" system, generally consist of academic papers, articles, and conference proceedings. In the "technology" system, there are two kinds of information: (1) hardware and other products represent physically encoded information and (2) verbally encoded information which result in patents.

This dissertation focuses only on verbally encoded information of both systems (e.g., academic papers, articles, conference proceeding, and patents). Hardware output is harder to collect and study. On the other hand, verbally encoded information is kept systematically. We employ a "bibliotech" technique in this study, which we will discuss more in the next section.

2. Verbally Encoded Information

2.1 Paper Literature

The use of literature to understand the growth of a field has a long and well-established tradition. Rappa and Garud (1991) state that Cole and Eales were among the first serious ones to utilize the published literature in order to quantify the progress in a field. When they published their study of the development of comparative anatomy in 1917, the two scientists examined nearly 6,500 books and papers to compile their data. The result was a detailed statistical account of the ebb and flow of research in comparative anatomy over three centuries. Cole and Eales clearly illustrated the prevalence and magnitude of cyclical changes in the level of publication activity that occur in a field over time.

Wilson and Fred are scientists who used the same methodology as Cole and Eales. They studied the subject of nitrogen fixation by plants in 1935. They put an intuitive grasp of the value of the literature by adding prediction of future trends in their research. Recently, literature-based studies of emerging fields of science and technology have become common (Rappa and Garud 1991, References therein).

Generally, there are two basic types of studies. The first type studies a model of the growth of technology by measuring annual publication volume. The second type studies the development of clusters of researchers in a technology by using citations as a unit of analysis. Actually, both types of literature studies cover a wide range of topics in science and technology. Recently, patent literature is an interesting literature that many researchers study.

Since the literature is a rich source of information, many researchers use the literature as a source of data about what goes on in the research community. There are many ways of studying. Mullin (1972) analyzes the literature to take advantage of the incidence of co-authorship and to understand the communication network that forms among researchers in a field. Spigel-Rosing (1972) analyzes the literature to identify individual researchers in order to compare the level of scientific manpower in different countries (Rappa and Gurud, 1993).

Comroe and Dipps (1976) also analyze the literature to understand the contribution of long-term basic research to major advance research in clinical medicine. Rappa and Gurud (1991) use the literature to determine the length of contribution spans of individual researchers in an emerging technology. Rappa and Gurud (1993) still use the literature as a source of data to analyze the length of researchers' association with a technology to examine persistence behavior.

The pros and cons of using a literature database as a source of communication are listed below (Yamada 1990):

Pros

- Researchers themselves have generated data.
- Geographically dispersed, mass of researchers can be accessible.
- A data set can be found easily by using key words.
- Not only demographic but also technological information can be obtained from the title and the abstract.
- The format of data is well established.

Cons

- Information communications are completely ignored.
- The time delay between a progress and a publication might be substantially long in some cases.

- - Individuals participating in a community cannot be discovered until he/she publishes something in the community.

2.2 Conference Proceedings

Scientists and engineers contribute their knowledge not only through published papers but also in conferences. Some conferences have set reviewers who are authorized to accept or reject contributions. According to a variety of contributions and a limitation of time in each conference, the reviewers select or group the contributions. The severer the review becomes, the more formality results.

By its nature, conferences are an oral expression. Participants have a chance to respond to each other immediately. They gather information from each other face-to-face, therefore, a conference is a semi-formal communication form. The conference is filled in a gap between literature-only (e.g., articles and published papers) and oral-only communication (e.g., talking and discussion) forms. Participants have documents in hand and are able to ask questions.

Basically, conferences are set for scientists, engineers, and people interested in technology. Sometimes we can observe an emerging technology from the title of the conferences and how often they occur. The title of conferences often has interesting topics in a specific field. Technology gatekeepers can meet scientists and engineers in the conferences directly.

How do researchers who do not participate in a conference get knowledge? Some conferences do not publish their contributions to the public but some conferences do. Conference proceedings are a type of reprinted contribution. We may consider the Best Paper Proceedings of the American Academy of Management as an example. The paper or conference proceeding is selected from conferences' contributions. Furthermore, scientists and engineers not only contribute their knowledge in conferences, but in articles and academic papers as well. Therefore, we can trace their knowledge through a variety of media.

2.3 Patents

Patent documents have several advantages as a "technology indicator." Patents provide rich information such as the name of the patent's owner, countries, issue date, abstract, patent classification of a given technology, references, and figures. Patent databases are used in many applications. They are rival analysis, technology tracking and forecasting, identifying important developments, international strategic analysis, infringement monitoring, and current awareness.

Patent statistical analysis is useful in sketching the "big picture" of activity in a technology. Because not all inventions are patented, patent analysis should be used as an additional piece of information to confirm or question technology (Mogee, 1991). We believe that if scientists and engineers need to contribute their knowledge to R&D communities, they will find a way to contribute it through a variety of media such as academic papers, and conference proceeding.

3. Brief Description of the Semiconductor Laser Diode

We choose a semiconductor laser diode R&D community to study the persistence. Semiconductor laser diode is one of many materials which is able to emit laser. As we know, the semiconductor is an important material in electronic devices. This material is developed and employed for long time. We will briefly describe of the semiconductor laser diode in this section.

The semiconductor industry is an excellent example of a growing and innovative industry (Malerba, 1985). There are a variety of major and minor innovations and technological improvements. The semiconductor industry lies at the core of the electronics industry. Technological change in the industry has affected technological change in the computer, telecommunication equipment, electronics consumer goods and industrial/medical/professional equipment industries. The industry has also become a strategic industry for international competitiveness.

To achieve the laser operation, a cavity filled with laser medium is prepared. Then the medium is pumped up by an outside energy source to an excited state. At this state, the medium will relax its atomic energy by releasing spontaneous radiation (R-Radiation) and then come down to the ground state. The spontaneous radiation is light (L-Light). Laser beams have been produced in every color of the rainbow (Hecht and Teresi 1982).

While initial spontaneous radiation passes through the cavity of medium, it stimulates (S-Stimulate) the other emission (E-Emission). The phase of the stimulated emission is the same as the first spontaneous radiation. This makes it seem like the first spontaneous light is amplified (A-Amplify) by the stimulated emission. Prepared surfaces of the cavity of medium works as high reflective mirrors. The only light, which is perpendicular to the mirrors, can repeat the pendulum motion from one surface to the others. Finally, the laser light comes out from the medium.

Materials used to produce the light are as follows (Harry, 1974; Luxon and Parker, 1985; and Gibiliso, 1989):

1. Crystal and glass lasers
2. Gas lasers
3. Excimer lasers
4. Chemical lasers
5. Optically pumped gas lasers
6. Semiconductor lasers
7. Liquid lasers
8. The free-electron lasers
9. The X-ray lasers.

Semiconductor laser technology is claimed to be the fastest moving laser technology in the 1980s. The first commercial semiconductor laser able to emit a continuous beam at room temperature entered the market in 1975 (Hecht and Teresi, 1982). This technology is one of the core technologies in electronic industries.

One emerging technology in the semiconductor laser field is called optical information processing. This technology treats data as a form of light rather than as an electrical voltage or current. It has the potential of faster processing speed compared with the conventional electronic information processing. We use fibre optics to transmit signals in optical instrumentation, communication, and laser beams. Fibre optics have good physical properties. They absorb light in small amounts (Luxon and Parker, 1985).

Three main reasons that caused the success of optical fibre transmission systems are as follows:

- high modulation rate of the output light
- matching of light wavelength to the low loss region of optical fibre
- easy maintenance especially for repeaters due to the built-in mirrors at the laser cavity ends.

Semiconductor laser diodes are also utilized in computers and printers. Using the optical fibre transmission technology, high-speed data transfer between a central computer and peripherals including terminals and printers is possible. The low cost and the portability of the semiconductor laser diodes are the reasons for this significant success. This technology is also used in entertainment and image recordings, since a high-speed data transfer is required in these products.

3.1 A Brief History of Early Development

The first laser diodes were demonstrated at IBM, MIT, and General Electric (GE) in 1962. They were operated only at cryogenic temperatures in pulses, an ill-suited condition for commercial applications. Therefore, most researchers focused on how to improve the physics of laser diode fabrication to operate at room temperature.

Finally, a semiconductor laser diode that can operate at room temperature was demonstrated by Bell Labs in 1970. Many institutions became interested in researching laser diodes in the early to mid –1970s. They were IBM, Bell Labs, NEC, NTT, Mitsubishi, Matsushita, Xerox, Sony, Sharp, Hitachi, Toshiba, Philips, MIT, University of Illinois, Hewlett-Packard, and the Soviet and American government labs.

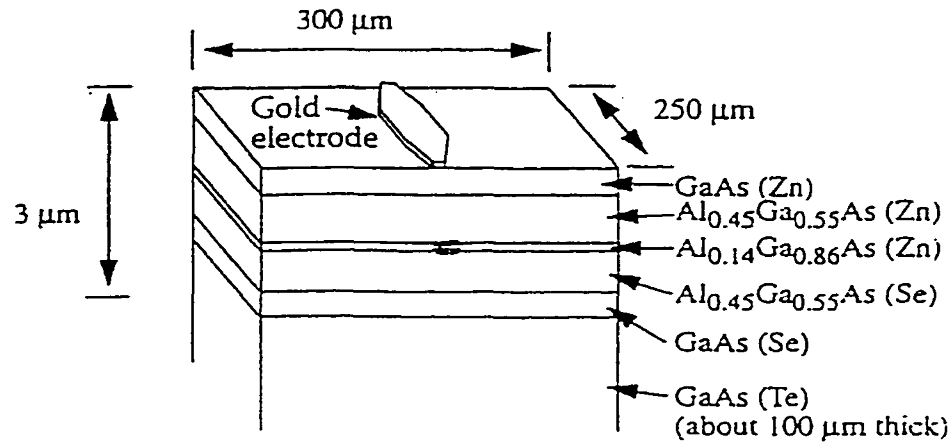
Although the semiconductor laser diode could operate at room temperature, it could only operate for a short time. Additionally, laser diodes were prohibitively expensive, unreliable, and available only in small quantities. There was also a problem with how to expand the range of wavelengths of different laser diodes. The researchers had to overcome both the physical properties of the semiconductor laser diode and its production problems. Most researchers were optimistic that as the technology became more understood, these significant problems could be solved.

Research focused on the physical properties driving important performance area such as output optical power, input electrical power, and light beam characteristics. At that time, the researchers often built process equipment themselves. A small company named Laser Diode Laboratories sold the first laser diodes with a lifetime of 500 hours (Hecht and Teresi, 1982). To be used in most commercial applications, the lifetime of a laser diode should be at least ten thousand hours. Therefore, the laser diodes were expensive. Their cost was more than $1,000 each.

Nowadays, the semiconductor laser diodes can operate at room temperature for more than ten thousand hours and their prices are relatively inexpensive. The difference in prices of the semiconductor laser diodes depends on the types of diode lasers. Regardless of their end-user applications, all diode lasers are decreasing in price. The price of diode lasers that operate between 700 – 800 nm is only about $1 (Frost & Sullivan, 1994).

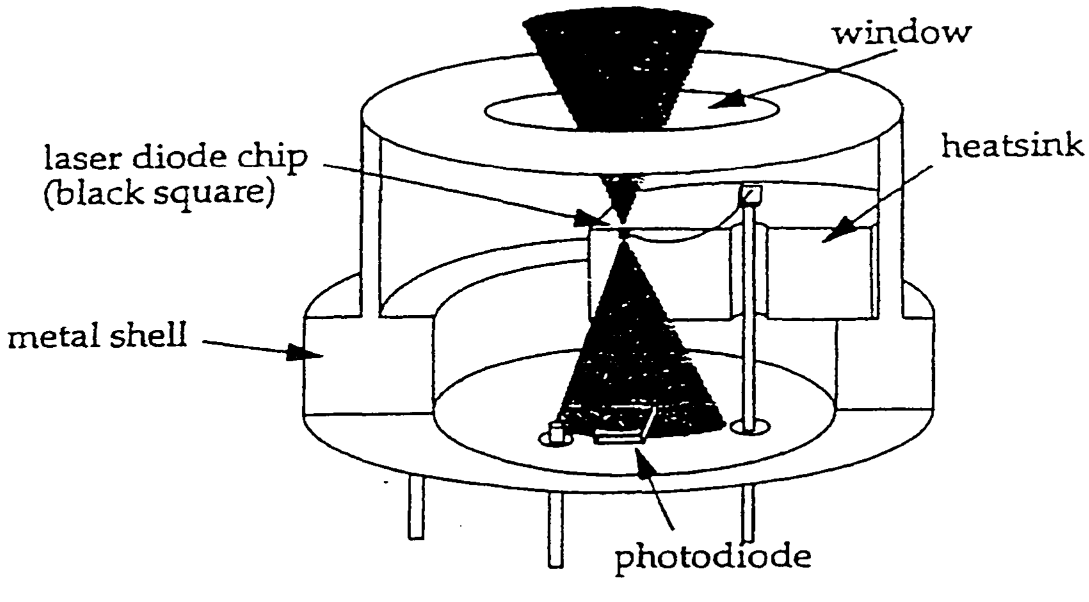
3.2 Fabrication of the Semiconductor Laser Diode

The semiconductor chip has to be placed in a package that connects the diode to other devices. The package includes heat sink and other components. Since the semiconductor uses many materials, the diode chip consists of a series of films of different alloys of gallium (GA), aluminium (AL), and arsenic (AS) deposited on a wafer, as shown in Figure 13. Following, Figure 14 shows a cut-away of a laser diode in its package.



Cross section of a laser diode chip with the vertical dimension expanded. Elements shown symbols in parentheses are added in small quantities. The shaded region is where light is emitted. One micron is equal to one ten thousandth of a centimetre.
Source: Wood, S.C., "The development of Laser Diode at Sony," Stanford GSB Case. S-OIT-8, 1995, p.3.

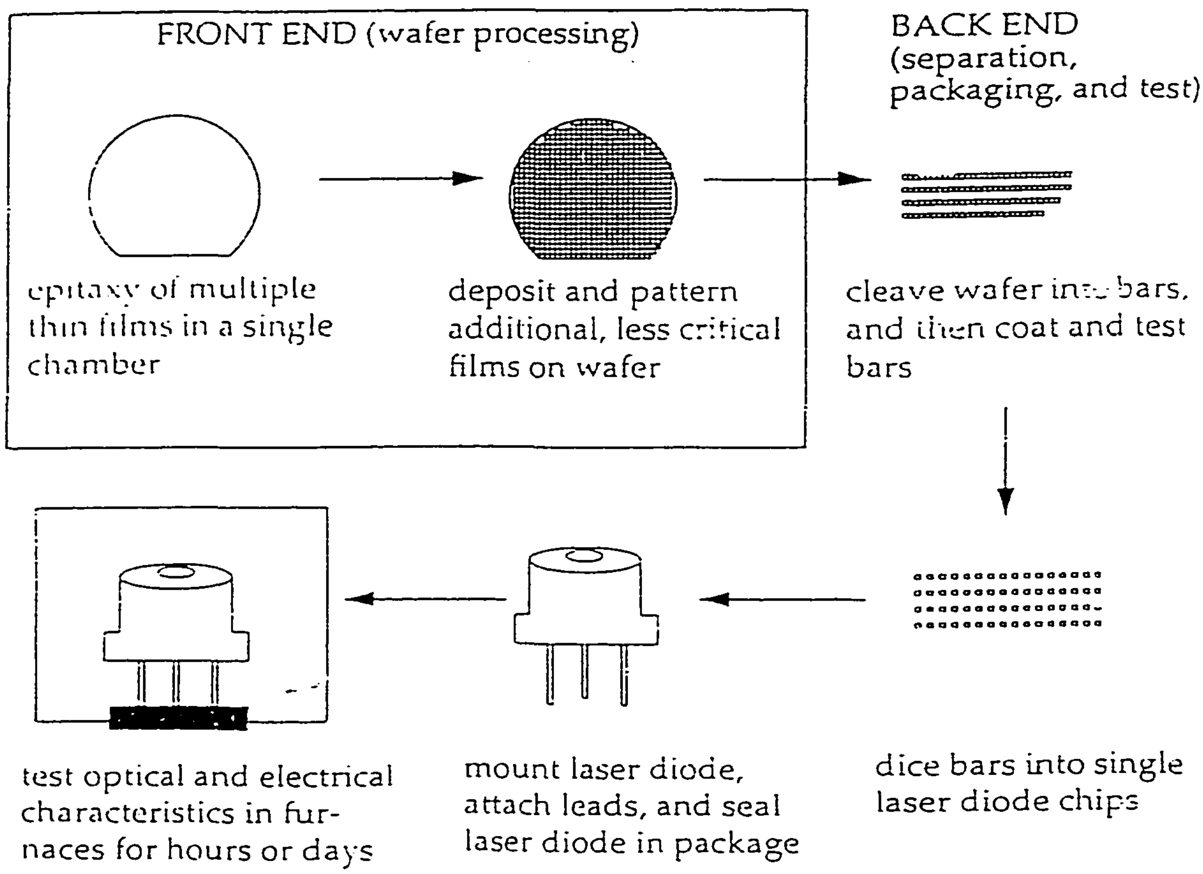
Figure 13: Cross Section of a Laser Diode Chip



The light emitted from the laser diode is shown by the shaded region. Early versions of this package were 9 millimetres in diameter.
Source: Wood, S.C., "The Development of Laser Diode at Sony," Stanford GSB Case, S-OIT-8, 1995, p.4.

Figure 14: Cut-Away of Packaged Laser Diode

The manufacturing sequences of a laser diode are provided in Figure 15. The sequence starts with a round or square wafer approximately 2 cm across. The first step is called "epitaxy." The wafer is processed using other tools that add, modify, and pattern additional, thicker films onto the wafer. Many processes are performed on the intact wafer to make up the "front-end" process. One wafer can contain about 20,000 identical laser diodes.



Wafers are processed in the "front-end" of the sequence, and then cut into diodes and packaged in the "back-end."
Source: Wood, S.C., "The Development of Laser Diode at Sony," Stanford GSB Case, S-OIT-8, 1995, p.4.

Figure 15: Laser Diode Manufacturing Sequence

The "back-end" process begins with the wafer being cleaved into bars. Each bar is one-diode wide, and roughly 100 diodes long. Each bar is then coated with film. At this point, the laser diodes are tested for functionality for the first time. The malfunctioning diodes are marked. The bar with working diodes is diced into individual chips. Each diode is mounted on a heat sink and connected to the electrical leads in the package.

The package is then sealed. At the end of this process, the laser diode is tested many times to verify electrical and optical characteristics and lifetime requirements. Any laser diodes that do not pass the test are discarded. The remaining fraction of laser diodes is the yield of the manufacturing process.

Most of the defects occur in the wafer epitaxy process. The ultimate lifetime and functionality of the laser diodes are very sensitive to the thickness, composition, and purity of the different deposited films and to the abruptness of the interfaces between the films.

A semiconductor laser is a laser produced by a semiconductor material. The semiconductor material is electrically pumped using a forward-biased p-n diode structure, and charge carriers injected into a thin active layer providing the optical gain. This structure does not necessarily require an external cavity, therefore, the semiconductor laser diode chip is about 100-300 micron in size.

Most diode laser media are fabricated from gallium arsenide (GaAs) and its derivatives, and from indium phosphide-based compounds (Frost & Sullivan, 1994). Diode lasers may be categorized according to wavelength: visible (less than 750 nm), near infrared (750-1,000 nm), and long wavelength (more than 1,000 nm). GaAs-based diodes produce lasers with wavelengths between 630-1,050 nm. Indium phosphide diodes produce lasers with wavelengths between 1100-2,100 nm. Lead salt diodes produce lasers with wavelengths between 2,500-12,500 nm.

3.3 Development of Some Types of Diode Lasers

Blue diode lasers (ZnSe) are some of the interesting products under development in the diode market. Blue diode lasers emit at 470 nm, whereas, the red diode lasers emit at 780 nm. Therefore, the blue diode lasers have shorter wavelengths than the red. It is an advantage because the shorter the wavelengths they have, the smaller the focal points they need. Therefore, if the blue diode lasers are developed and used instead of the red diode lasers, data capacities will increase.

HeNe lasers are used in many detectors and measurement systems. The lasers emit at 670 nm. Diode lasers, which emit at 670 nm, are not as precise as the HeNe lasers. Although the diode lasers are not precise, their shorter wavelengths can create more brightness. Moreover, diode lasers can also generate low-power (1-megawatt) beams, which are more efficient than HeNe lasers. Therefore, the diode lasers will substitute for the HeNe lasers.

Tuneable diode lasers such as Ti: sapphire and dye tuneable lasers are competing with older technologies. These lasers are tuned by means of an external cavity grating. Therefore, these lasers can tune their wavelengths from 780 nm to 1060 nm. The tuneable diode lasers have higher reliability and lower cost than the old technologies. Because of these advantages, the sales of tuneable diode lasers will grow significantly (Frost & Sullivan, 1994).

4. Accessing R&D Community Records

The Database for Physics, Electronics and Computing (INSPEC), which is maintained by the Institution of Electrical Engineers (IEE) of the UK, is selected as a good resource. INSPEC contains citations with abstracts to the worldwide literature in computers and control, electronics and electrical engineering, information technology, and physics. Sources include more than 4,000 journals and more than 2,000 conference proceedings, books, and reports.

The data for this study was gathered by using these specific keywords: *laser diode, laser diodes, semiconductor laser, semiconductor lasers, semiconductor junction laser*, and *semiconductor junction lasers*. The patent database is also gathered by using the same keywords as the literature database and patent classification, which are categorized by the United States Patent Office.

One may question why we use the United States Patent database. It is because the United States is a technology leading country in the semiconductor laser diode. Many foreign technology leading firms (e.g., Sony and Sharp) have established their subsidiaries in the United States. Furthermore, the United States legal systems are powerful in order to protect their patents. Most firms prefer to register their patents in the United States. We believe that the United States Patent database is a good database to study the semiconductor laser diode technology.

The study uses a bibliographic software package called ProCite to analyze the databases. We put literature papers and conference proceedings database and patent database in the ProCite. The ProCite enables us to index the data by author and by author affiliation as well as publication date or any field in a record. Citations can be organized chronologically.

Since we access data by using a set of keywords, it is possible that some records are the same. ProCite can identify duplicated records by comparing authors, title, and date of publication fields. However, we know that some scientists and engineer contribute their knowledge through a variety of methods in different dates. We then check the records manually by comparing author and title fields.

5. Data Constraints

As stated earlier, we collect bibliography data by using the INSPEC database. We find that the database has limitations. The INSPEC database presents only the first author's organization. We cannot identify the rest of authors' organizations. However, we do not focus on organizations' manpower. Thus, this limitation does not affect our analysis.

One may question that the manpower (size) of organization may affect to its persistence. This may be true. If an organization has a greater number of researchers, they may conduct their research longer than other organizations. However, it is a limitation to find organizations' manpower throughout the world for more than thirty years.

Some records are not complete. For example, the authors' affiliations and types of published papers are not provided, although they are in the same electronic database and/or recently published. Therefore, we have to eliminate those incomplete records.

6. Data

We have collected bibliography data beginning in 1966 through 1998 using the INSPEC. We obtained 52,327 records, which include academic journals, and conference proceedings. We found that 66 countries contribute knowledge in the semiconductor laser diode R&D community. The US and Japan are leaders in the R&D community. They contribute 15,914 (32.313%) and 11,124 (22.587%) records respectively. We also found that 3, 071 organizations participate in the R&D community. Table 1 shows more details.

Table 1. Amounts of the literature of semiconductor laser diode R&D community by country (1966-1998)

No.	Country	Amount of Literature (papers)	Amount of organizations (oganizations)
1	Algeria	2	2
2	Argentina	6	4
3	Australia	163	31
4	Austria	171	12
5	Bahrain	7	2
6	Bangladesh	7	2
7	Belgium	287	6
8	Brazil	144	24
9	Bulgaria	66	9
10	Canada	1,062	75
11	Chile	1	1
12	China	1,285	128
13	Cuba	11	2
14	Cyprus	5	1
15	Czechoslovakia	129	17
16	Denmark	280	13
17	Egypt	10	5
18	Finland	157	15
19	France	2,333	154
20	Germany	3,570	308
21	Ghana	1	1

22	Greece	48	9
23	Hong Kong	89	6
24	Hungary	78	9
25	India	402	63
26	Iran	13	5
27	Iraq	2	2
28	Ireland	122	8
29	Israel	308	18
30	Italy	975	79
31	Japan	11,082	336
32	Jordan	3	3
33	Korea	520	66
34	Luxembourg	1	1
35	Malaysia	14	5
36	Mexico	30	10
37	Morocco	2	1
38	Netherlands	679	35
39	New Zealand	16	9
40	Nigeria	6	3
41	Norway	34	9
42	Oman	2	1
43	Pakistan	11	5
44	Philippines	2	1
45	Poland	335	25
46	Portugal	42	8
47	Qatar	1	1
48	Romania	64	15
49	Saudi Arabia	6	4
50	Singapore	112	4
51	South Africa	17	7
52	Spain	237	28
53	Sweden	408	23
54	Switzerland	598	21
55	Syria	1	1
56	Taiwan	328	26
57	Thailand	6	3
58	Tunisia	2	1
59	Turkey	24	9
60	UK	3,457	169
61	Uruguay	5	1
62	USA	18,778	922
63	USSR	3,728	284
64	Venezuela	7	2
65	Vietnam	9	3

66	Yugoslavia	24	10
	Total	49,250	3,071

In addition to the US and Japan, we find that there are only 10 countries that have "contribution shares" of more than 1%. They are Germany (7.105%), UK (7.027%), USSR (6.753%), France (4.745%), China (2.615%), Canada (2.067%), Italy (1.98%), The Netherlands (1.381%), Switzerland (1.214%), and (South) Korea (1.015%). Figure 16 shows a "contribution share" from the first ten countries.

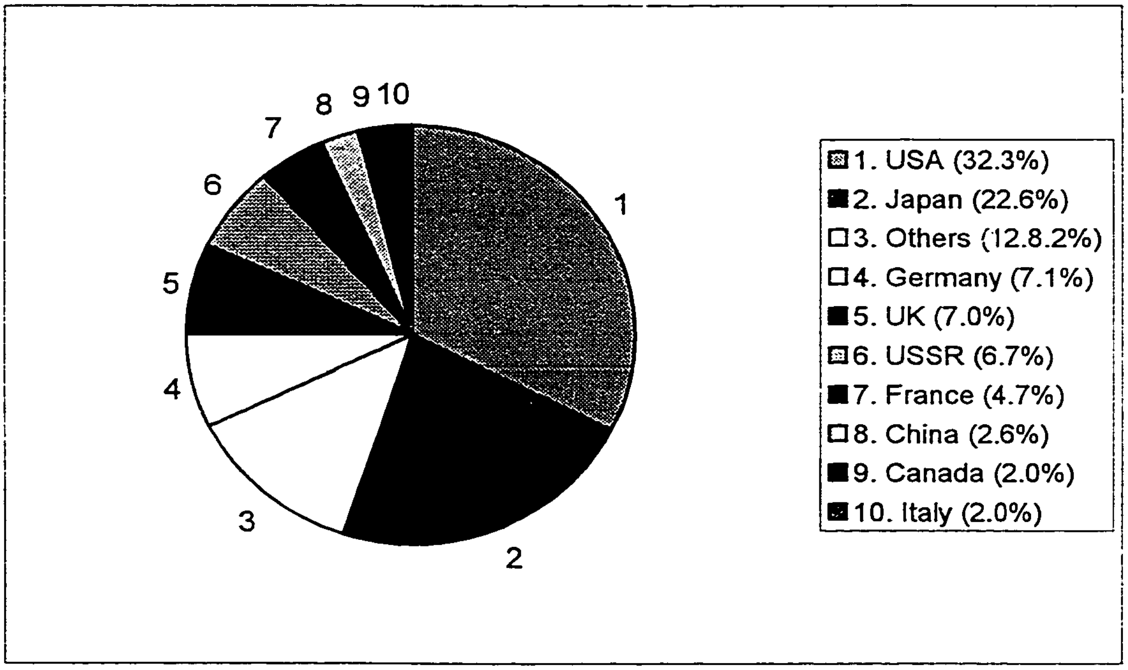


Figure 16: Contribution share of the major counties in the semiconductor laser diode R&D community (1966-1998)

In our patent database, we have collected patent data from the US Patent database beginning in 1969. We find that there are 22 countries that registered their patents in the US. We have 3,149 records. There are 506 organizations which registered their patents in the US Patent database. However, there are 125 patents from individuals in the patent database. Since our focus is on organizational units in the organizational level, we have removed them. Basically, we use a total of 3,143 patents in our analysis. Table 2 provides further details.

In the US Patent database, it should be noted that we classify each country by using the country field in the patent record. Some subsidiaries that are located in foreign countries may inform their home-base countries. Although it is possible that some of the subsidiaries' patents are innovated in the foreign countries, it is reasonable that the "mother" firms own the patents. For an example, the US Philips Corporation identifies its country as The Netherlands (NL). Since the US is a technology leading country, the Philips Corporation needs to register its patents in the US.

Table 2. The amount of semiconductor laser diode patents of each country in the US Patent database (1969-1998)

Country	Amount of patents	Percentage (%)
Australia	5	0.159
Austria	2	0.064
Belgium	1	0.032
Brazil	1	0.032
Canada	28	0.889
France	65	2.064
Germany	111	3.525
Hungary	1	0.032
Ireland	1	0.032
Israel	5	0.159
Italy	9	0.286
Japan	1557	49.444
Korea	70	2.223
Malaysia	2	0.064
Netherlands	52	1.651
Sweden	3	0.095
Switzerland	16	0.508
Taiwan	10	0.318

UK	42	1.334
USA	1164	36.964
USSR	4	0.127
Total	3149	100.000

It is interesting that a group of Japanese organizations are the largest group in the US Semiconductor Laser Diode Patent database (1,557 patents or 49.444%). The US and Germany are the second and third rank, respectively. The US organizations and Germany's organizations have 1,164 (36.964%) and 111 (3.525%) patents respectively. From both Tables 1 and 2, we may deduce that Japan and the US are technology-leading countries in the semiconductor laser diode technology.

We find that there are only five countries, besides Japan and the US, which have "contribution shares" of more than 1% in the semiconductor laser diode US patent database. They are France (2.064%), Germany (3.525%), South Korea (2.223%), the Netherlands (1.651%), and UK (1.334%). Figure 17 summarizes the "contribution shares" of countries in the US Patent database.

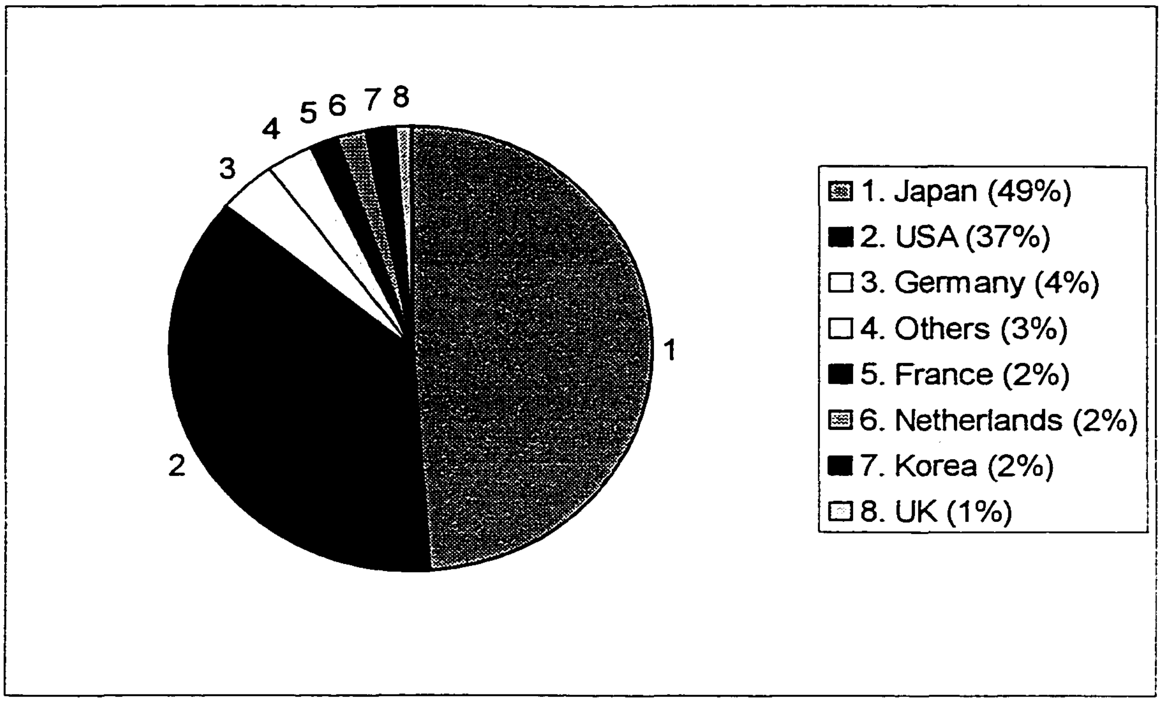


Figure 17: "Contribution shares" of countries in the US Patent database (1969-1998)

7. Measurement

7.1 Individual Hypotheses

Dependent Variable

The dependent variable, PERSIST1, is the number of years in which a researcher persists in the R&D community by considering the number of years that have elapsed from the first to the last publication for each author. For example, if a researcher first published in 1980 and last published in 1990, the number of years that a researcher persists in the R&D community would be calculated as eleven years.

Independent Variables

Hypothesis H1 states that the greater sunk cost a researcher invests, the greater persistence he tends to have. We consider a researcher's sunk cost by using the number of literature that he publishes. Researchers have to invest their time, energy, and other resources to conduct their research. The number of literature that a researcher published are counted and put in a COMMIT1 variable.

Hypothesis H2 states that the greater technological networks a researcher works with, the greater persistence he tends to have. In this dissertation, the technological network is defined as the number of co-authors that a researcher works with. Basically, researchers usually work with other researchers. Since R&D is complicated, they can share and exchange their knowledge, therefore, we count the number of co-authors that a researcher works with. We then put the number of his co-authors in a NETWK1 variable.

Hypothesis H3 states that the greater number of experimental papers a researcher publishes, the greater persistence he tends to have. We identify types of published papers (treatment) such as theoretical or mathematics, general review, new development, and experimental papers. Thus, we count the amount of experimental papers that a researcher has published. We put an amount of experimental papers of each researcher in an EXPER1 variable.

Hypothesis H4 states that the greater research diversity a researcher publishes, the greater persistence he tends to have. We consider research diversity by using the number of class codes that a researcher conducts. Therefore, we count the number of areas (class codes) of a technology that a researcher conducts and put it in an AREA1 variable.

Hypothesis H5 states that as the more published papers that are related to the technological characteristics of a researcher conducts, the greater persistence he tends to have. According to semiconductor laser diode technology's characteristics, it is a material-basis technology. Therefore, we count the number of literature that is related to material and put it in a MTRL1 variable.

Hypothesis H6 states that the greater reputation a researcher acquires, the greater persistence he tends to have. As discussed earlier, journals are the most popular resource that researchers use to study. We count the number of literature that a researcher publishes in journals and put it in a REPUTE variable.

7.2 Organizational Hypotheses

Independent Variable

We use the same independent variable as an individual independent variable, since we consider the persistence of organization in the semiconductor laser diode R&D community. PERSIT2 dependent variable is created. PERSIST2 is the number of years that have elapsed from the first to the last publication which an organization contributes its knowledge to the R&D community.

Dependent Variables

Hypothesis H7 states that the larger amount of the literature an organization contributes to the R&D community, the longer persistence it tends to have. We count the total amount of papers and patents that an organization contributes and put it in a TOTAL2 variable.

Hypothesis H8 states that if an organization is located in an area with a high density of knowledge, it will tend to persist longer than an organization located in an area with a lower density of knowledge. We categorize each area by country. This means that we count the total number of papers and patents that are published by people in each country. The figure is put in a GEOGPH2 variable. This means that organizations that are located in the same country have the same figure in this variable.

Hypothesis H9 states that the greater the technological capability an organization has, the longer persistence it tends to have. We consider the total amount of patents that an organization contributes to the R&D community. The figure is put in a PATENT2 variable.

Hypothesis H10 states that academic researchers are more likely to persist in the R&D community longer than other researchers. We have categorized organizations into three groups. They are firms, academic, and governmental laboratory groups. FIRM, UNIV, and GOV dummy variables are created. For an example, if an organization is a university, we will put one (1) in a UNIV variable. The rest of them are put zero (0).

7.3 National Measurement

Dependent Variable

A dependent variable of this unit of analysis is the same as the individual and the organizational units of analysis. We change a dependent variable's name into PERSIST3. The PERSIST3 is the number of years that a nation contributes knowledge to the R&D community. We also make an assumption that any individual or organization which is located in a country, is considered as a resource of the country where it is located. For an example, Sony firms, which are located in the US, are considered as the US's firms.

One may have a question about this assumption. We consider this assumption seriously. Once foreign firms are set up in a country, they are looking for some advantages such as marketing, knowledge, and labor. This means that the country has appropriate facilities and environment. Furthermore, most foreign subsidiaries always contact and work with local researchers. Almeida (1996) states that foreign firms not only take advantage, but also contribute their knowledge to local technological progress.

Independent Variables

Hypothesis H11 states that the greater amount of literature that is published by a nation, the longer persistence the nation tends to have. To measure this hypothesis, we consider the total number of published papers and patents that are published in a country. This figure is put in a TOTAL3 variable.

Hypothesis H12 states that the greater amount of manpower in a nation, the longer persistence the nation tends to have. To measure this hypothesis, we collect the number of researchers who published papers in a country. One may question about how we classify Ph.D. students who study in foreign countries. We consider them as researchers who work in the countries that they study. Researchers cannot conduct their research without appropriate facilities and environment. We put this figure in a MPOWER3 variable.

Hypothesis H13 states that the greater amount of technological sub-fields of a given technology, the longer persistence the nation tends to have. To measure this hypothesis, we collect the amount of technological sub-fields of published papers that contribute by individuals or organizations in a country. Technological sub-fields are provided in class codes field of literature data. This figure is put in an AREA3 variable.

Hypothesis H14 states that the greater number of organizations in a nation, the longer persistence the nation tends to have. To measure this hypothesis, we collect the total amount of organizations (e.g., firms, universities and governmental laboratories), which are located in a specific country. We also employ the assumption that we discussed in the Hypothesis H11. Foreign subsidiaries are considered as organizations in a country where they are located. This figure is put in an ORG3 variable.

Hypothesis H15 states that the higher individualism work value in a nation, the longer persistence the nation tends to have. Since we study the degree of individualism or collectivism in each paper. The relevant areas of technology or researchers' name in a paper may be the same as those of other papers. We divide the total number of relevant areas of a technology (or technological sub-fields of a specific technology) of the published papers by the total number of researchers in a country.

For example, Country X has published two papers. There are 4 researchers who published 10 relevant areas of the technology in the first paper. There are 3 researchers who published 6 relevant areas in the second papers. Therefore, the figure that we derive for the country is 2.25 ([(10 / 4) + (6/3)]/2) relevant areas per researcher. The figure is put in a CULTURE variable.

8. Contribution to Knowledge

This dissertation builds upon and extends the persistence literature in three ways. First, it tests the validity of the "bibliotech" technique in order to study the persistence of researchers in an R&D community. Bibliography data, generally, is used in institutions. It is easy to access, and provides rich information.

Second, this dissertation constructs new interested variables such as the treatment of publication and relevant areas of a technology (class codes) that researchers conduct. These variables cannot be easily taken or derived from questionnaire surveys. This information is created by publishers and/or some specific associations to classify the publications and the technology.

Third, this dissertation explores factors that affect the persistence of individuals, organizations and nations in the semiconductor laser diode technology. The semiconductor laser diode technology is a well-developed technology. This dissertation is an empirical study. Many studies that discuss an international framework usually propose only ideas without supporting data (see Lynn, Aram, and Reddy, 1997; Lynn, Reddy, and Aram, 1996; Padmore, Schuetze and Gibson, 1997; Dunphy, Herbig, and Howes, 1996; Teece, 1994). This dissertation explores some factors with supporting data. Policy makers and business planners may consider the influential factors with other studies. We believe that our study may provide some significant evidence to R&D community.

CHAPTER V

RESULTS

Before delving into the measurement section, we will briefly examine the Semiconductor Laser Diode R&D community. This will facilitate a more thorough understanding of the data.

1. The Semiconductor Laser Diode R&D Community

As mentioned earlier, the semiconductor laser diode is a well-developed technology. Scientists and their organizations, including their governments, have studied this technology since 1966. We classify members of the semiconductor laser diode R&D community into three levels (units): individual, organizational, and national. Each unit is studied in a later section.

In order to show an overall picture of the semiconductor laser diode R&D community, we present some figures about the units of analysis in this section. Figure 18 provides the amount of publications published each year from 1966 to 1998. Figure 19 shows the amount of researchers who contributed their knowledge to the semiconductor laser diode R&D community from 1966 to 1998. The numbers of organization who have contributed their knowledge to the R&D community is given in Figure 20. Finally, Figure 21 shows the numbers of nations that have joined the R&D community each year from 1966 to 1998.

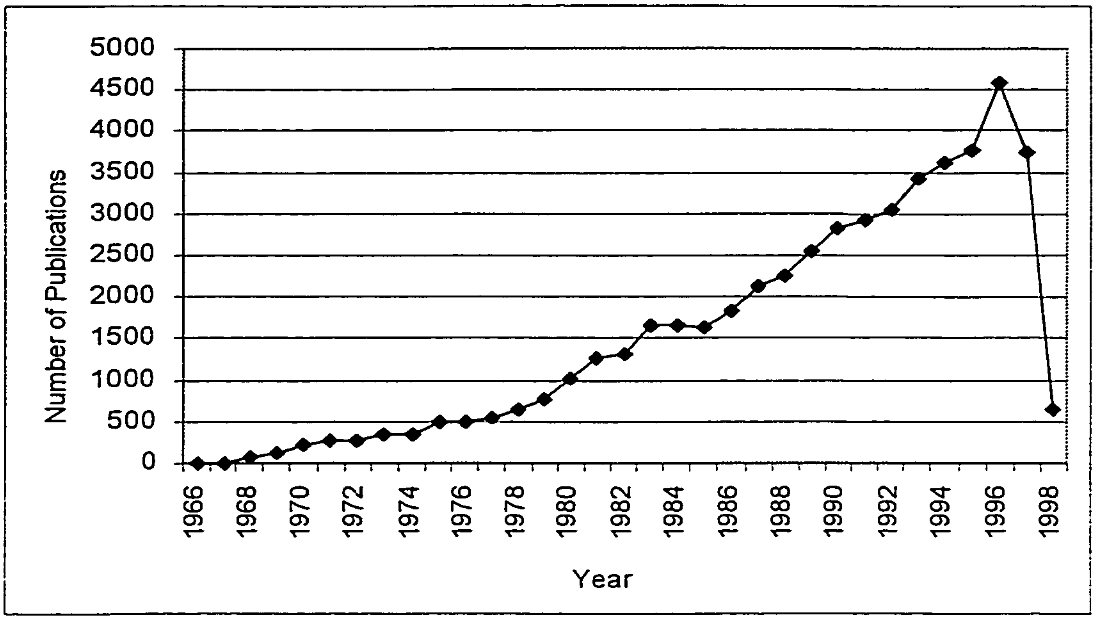


Figure 18: The Amount of Publications in the Semiconductor Laser Diode R&D Community (1966 – 1998).

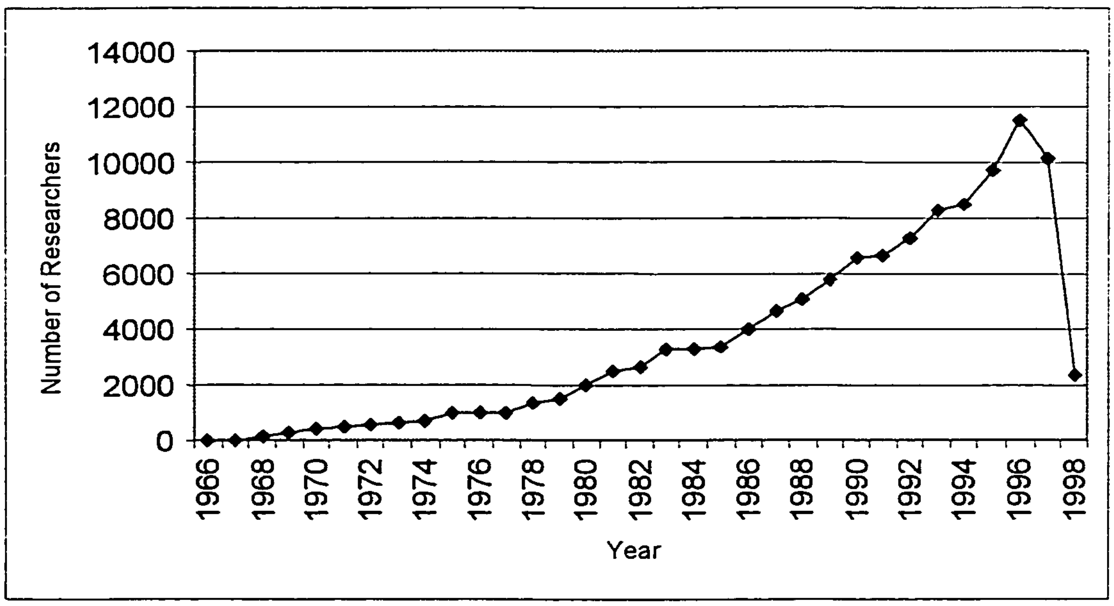


Figure 19: The Amount of Researchers in the Semiconductor Laser Diode R&D Community (1966 – 1998).

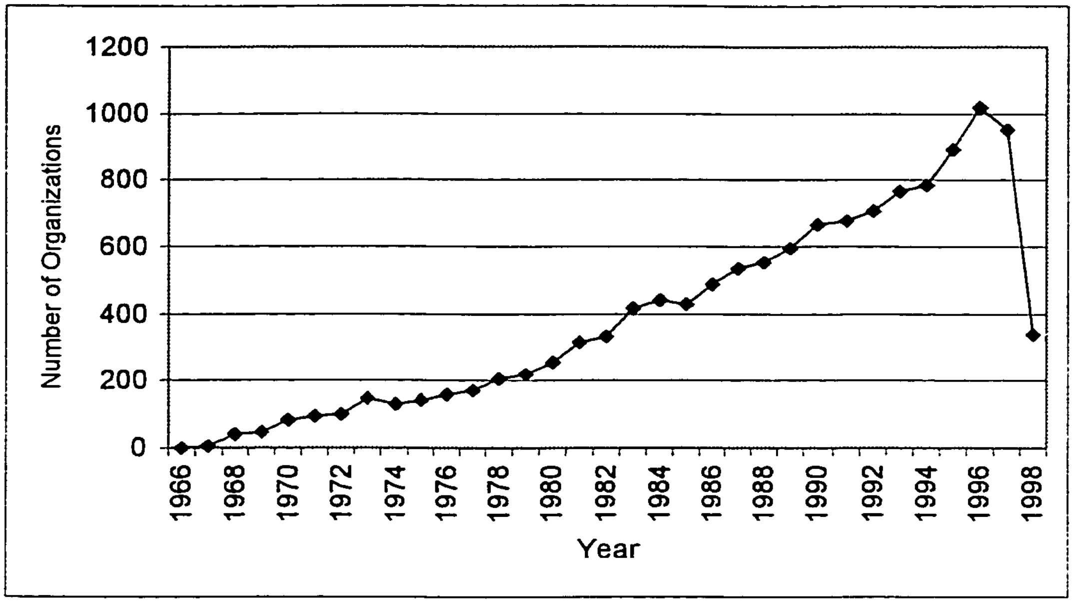


Figure 20: The Number of Organizations in the Semiconductor Laser Diode R&D Community (1966 – 1998).

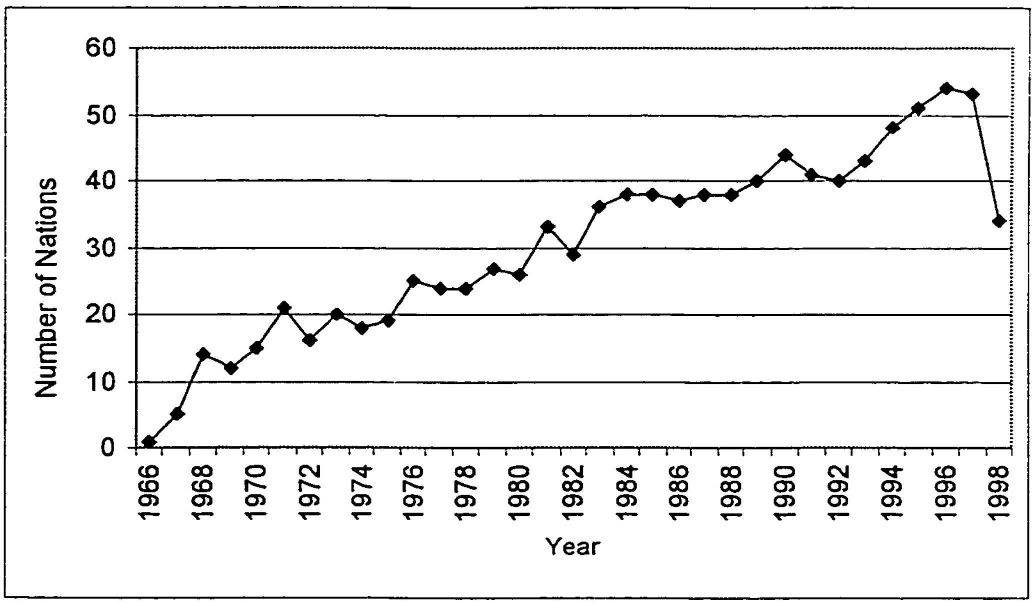


Figure 21: The Number of Nations in the Semiconductor Laser Diode R&D Community (1966 – 1998).

These figures illustrate the same trend. The numbers of publications, researchers, organizations, and nations in the semiconductor laser diode R&D community increased from 1966 to 1996. It is interesting that all of the highest points in all of the graphs occurred in 1996. Then, they abruptly decreased in the next two years (1997 and 1998), especially, the data of 1998 which declined drastically. Before we study the overall data further, we must discuss the data in the last two years of this study.

Based on our methodology, we do not consider the data of 1998 because we understand that there must be a few delays from submitting to publishing. Generally, it takes about half a year to one year in this process. Since we employ the "bibliotechnique" in this study, we have to consider this problem. Therefore, we will take out the data from 1998, but will keep the data from 1997.

From Figure 18 to 21, we observe that all graphs reach their peak in 1996 and begin to decline in 1997. According to the Product Life Cycle model in section 2.3.1, we consider that the semiconductor laser diode R&D community is in its maturation stage. This provides a good opportunity to study its members' persistence. For the members persisting in the R&D community, the factors influencing their persistence will be examined more thoroughly.

2. The Individual Persistence

The first unit of analysis is the individual unit. Although the numbers of researchers who have contributed their knowledge to the R&D community increase every year, it is not necessary that the same researcher will contribute his/her knowledge every year. Some researchers may quit the R&D community. On the other hand, some may persist in the R&D community.

In order to study the individual persistence, we set our study framework by focusing on six interested factors: *(1) sunk cost, (2) technological network, (3) experimental work, (4) research diversity, (5) technological characteristics,* and *(6) reputation*. As discussed previously, we determined how to measure each factor in section 4.7.1. Table 3 summarizes how we measure each factor.

Table 3 Measurement of the Six Individual Factors

Factors	Measurement
1. *Sunk Cost* (COMMIT1)	1. a total amount of literature (papers)
2. *Technological Network* (NETWK1)	2. a total amount of co-researchers who work with a researcher (persons)
3. *Experimental Work* (EXPER1)	3. a total amount of experimental literature that a researcher contributes (6 types of treatment: A, G, N, P, T, and X)
4. *Research Diversity* (AREA1)	4. a total amount of class codes that a researcher conducts (areas)
5. *Technological Characteristics* (MTRL1)	5. a total amount of literature that is related to material (papers)
6. *Reputation* (REPUTE)	6. a total amount of literature that is published on journals (areas/person)

In order to study the factors, we employ linear regression analysis in our study and thereby develop a regression equation based on the hypotheses. The regression equation consists of one dependent variable and six independent variables. The equation is shown in the equation (5.1).

$$PERSIST1 = \alpha_1 + \beta_1 COMMIT1 + \beta_2 NETWK1 + \beta_3 EXPER1 + \beta_4 AREA1 + \beta_5 MTRL1 + \beta_6 REPUTE + \delta_1 \quad (5.1)$$

whereas:

α_1: a constant value

$\beta_1, \beta_2, \ldots, \beta_6$: coefficient value of each factor

δ_1: an error value of the regression

PERSIST1: the individual persistence

COMMIT1: the sunk cost factor

NETWK1: the technological network factor

EXPER1: the experimental work factor

AREA1: the research diversity factor

MTRL1: the technological characteristic factor

REPUTE: the reputation factor.

We will first explore our data set by using descriptive statistics. We find that there are 59,267 researchers in the semiconductor laser diode R&D community. We find that the mean of PERSIST1 variable is 3 years. On average, a researcher contributed his/her knowledge in 3.11 papers and 9.33 relevant areas. Table 4 provides the statistical details.

Table 4 Descriptive Statistics of the Semiconductor Laser Diode R&D Community: The Individual Level

Variables	Minimum	Maximum	Mean	Std. Deviation
PERSIST1	1	31	3.00	4.19
COMMIT1	1	305	3.11	7.19
NETWK1	0	251	7.68	10.31
EXPER1	0	240	2.54	5.92
AREA1	0	159	9.33	9.26
MTRL1	0	253	1.99	4.99
REPUTE	0	251	1.94	5.25

N: 59,267 researchers

Additionally, the statistics in Table 4 found one researcher who has 7.81 co-authors on average. There is one researcher who published 305 papers over 29 years. The maximum persistence of the R&D community is 31 years. We also find that on average, a researcher has published 2.54 (81.67% of 3.11 papers) experimental papers, 1.99 (63.98% of 3.11 papers) material-related papers, and 1.94 (62.37% of 3.11 papers) journal papers.

We find that 70.65% of the data set (49,250 records) are journal papers. The percentages of these variables show some degree of relationships among them. One can estimate that the relationship between COMMIT1 and EXPER1 is quite high (81.67%). We continue to analyze the relationship among these variables in the next section.

2.1 Correlation Analysis

We have found the relationship among dependent and independent variables in the last section based on basic information of the descriptive statistics. In order to study the relationship among the dependent and the independent variables of the model directly, we employ the correlation analysis technique with our model. The correlation analysis is a useful tool not only to indicate the relationship among the variables but also to inspect mullticollinearity in the model.

Since we employ the linear regression analysis in the study, it is necessary to test the correlation among the variables in the model. According to the linear regression's assumption, the least-squares estimators are unbiased and they have the smallest variances of any estimators. If one or more correlation values in a model are high, they may violate the assumption, therefore, correlation values should not be high. Table 5 provides the more specific details.

Table 5 Correlation in the Individual Regression

	PERSIST1	COMMIT1	NETWK1	EXPER1	AREA1	MTRL1	REPUTE
PERSIST1	1.000	0.576*** (.000)	0.598*** (.000)	0.564*** (.000)	0.680*** (.000)	0.547*** (.000)	0.544*** (.000)
COMMIT1		1.000	0.811*** (.000)	0.976*** (.000)	0.779*** (.000)	0.920*** (.000)	0.967*** (.000)
NETWK1			1.000	0.825*** (.000)	0.794*** (.000)	0.767*** (.000)	0.750*** (.000)
EXPER1				1.000	0.789*** (.000)	0.938*** (.000)	0.938*** (.000)
AREA1					1.000	0.737*** (.000)	0.703*** (.000)
MTRL1						1.000	0.887*** (.000)
REPUTE							1.000

***: Correlation is significant at the 0.01 level (2-tailed)
N: 59,291 researchers

In Table 5, we find that the relationship between the dependent (PERSIST1) and independent variables (COMMIT1, NETWK1, EXPER1, AREA1, MTRL1, and REPUTE) is in a positive direction significantly. All correlation values are significant at the level of 0.01 (2-tailed). This means that the results support our hypotheses significantly and furthermore, there are other significant relationships as we will discuss now.

The relationship between COMMIT1 and NETWK1 is significant at the level of 0.01. It is shown that a researcher who has published more publications, tends to have more co-authors. Our finding is also supported by Nonaka and Takeushi's (1995) study.

They believe that although new knowledge originates with an individual, the knowledge is amplified at the group and organizational level. Therefore, researchers who have more co-authors, tend to publish more publications.

The relationship between COMMIT1 and EXPER1 is significant at the level of 0.01. It is shown that a researcher who conducts many experiments is likely to publish many papers. We have found that the percentage of experimental papers in the R&D community is high (77.45%). This means that most researchers conduct experimental research in order to gain "tacit knowledge."

The relationship between COMMIT1 and AREA1 is significant at the level of 0.01. It is shown that a researcher who has a variety of knowledge is likely to publish many papers. This finding is not a surprising one. Basically, in order to publish more publications, a researcher has to present unique result to the R&D community. Therefore, he/she has to have a variety of knowledge.

The relationship between COMMIT1 and MTRL1 is significant at the level of 0.01. It is shown that a researcher who has conducted research that is related to materials is more likely to publish many papers. Since the semiconductor laser diode technology is a material basis technology, a researcher is likely to conduct research related to material technology.

The relationship between COMMIT1 and REPUTE is significant at the level of 0.01. It is possible that a researcher who has published in journals is likely to publish more publications. It is understood that researchers need recognition among themselves. The more publications, the better reputation and more recognition he/she achieves. Journals are the most popular media in the R&D community, especially academic journals. Furthermore, some organizations (e.g., universities) use the total amount of publications of researchers as one of the important criterion to evaluate their researchers' performance.

The relationships between NETWK1 and EXPER1, AREA1, MTRL1, and REPUTE are significant at the level of 0.01. It is shown that a researcher who has conducted experimental research, in a variety of research areas, material-related papers, or published in journals is likely to have more co-authors. It is possible that some of his/her co-authors may conduct experiment research. They may propose a variety of research areas in which they can work together. They also may use materials in their research. Finally, they need to contribute their knowledge through good, recognized journals.

The relationships between EXPER1 and AREA1, MTRL1, and REPUTE1 are significant at the level of 0.01. It is shown that a researcher who has contributed a variety of research areas, material-related papers, or published a journal papers, is likely to conducted experimental research. In experiments, a researcher can control variables and use a variety of materials in his/her research. Therefore, he/she can conduct a variety of research areas. Once the experimental research is completed, the researcher tends to publish in journals.

The relationships between AREA1 and MTRL1, and REPUTE1 are significant at the level of 0.01. It is shown that a researcher who has contributed material related papers or published in journals is likely to provide a variety of research areas. Because material knowledge is a core of the semiconductor laser diode, a researcher has to study and employ a variety of materials in research. Once the research is complete, the researcher tends to publish in journals.

The relationship between MTRL1 and REPUTE1 is significant at the level of 0.01. It is known that journals, especially academic journals, are the important media to study what other researchers are doing or have done. When researchers read colleagues' work, they may be refereed. It is possible that journal papers, contributed by a researcher, are likely to relate to material because material knowledge is a core knowledge of the semiconductor laser diode.

The correlation values among the independent variables are quite high. For example, the correlation between COMMIT1 and EXPER is 0.976 and the correlation between COMMIT1 and REPUTE is 0.967. As discussed in the previous section, the relationship among these variables is quite high. High correlation value (s) among independent variables may cause multicollinearity problems in the model.

We consider the correlation matrix carefully. The multicollinearity may exist in the individual regression. According to Montgomery and Peck's (1982) multicollinearity diagnostics, they propose three methodologies: (1) examination of the correlation matrix, (2) variance inflation factors (VIF), and (3) Eigensystem analysis of X'X. We will employ the first and the second diagnostics in our study.

The first diagnostic is a very simple measure of multicollinearity. We inspect the off-diagonal elements (r_{ij}) in the correlation matrix. If variables X_i and X_j are nearly dependent, then a correlation value ($|r_{ij}|$) will be near unity (1). It is quite difficult to identify how much of a correlation value ($|r_{ij}|$) is considered as a high correlation. Practical experience indicates that if any of the correlations exceed 0.95, it is an indication that the regression coefficients are poorly estimated because of multicollinearity (Dietrich, 1999 - interviewed).

We employ the correlation value of 0.95 as a criterion in order to consider whether the multicollinearity exists in our models throughout the study. We also consider that one or more higher correlations indicate multicollinearity. As mentioned earlier, the correlations between COMMIT1 and EXPER (0.976), and COMMIT1 and REPUTE (0.967) are near unity (1). Therefore, multicollinearty exists in the individual regression.

The second diagnostic is variance inflation factors (VIF). The VIF can be written as $C_{jj} = (1 - R^2_j)^{-1}$, where R^2_j is the coefficient of determination obtained when x_j is regressed on the remaining $p - 1$ variables and C_{jj} is the j^{th} diagonal element of the correlation matrix. Practical experience indicates that if any of the VIFs exceeds 10, multicollinearity exists in a model (Montgomery and Peck, 1982).

The third diagnostic is eigensystem analysis of $X'X$. Characteristic roots or eigenvalues of $X'X$, say $\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_n$, can be used to measure mullticollinearity in the data. Some analysts employ to use the condition number of $X'X$, defined as $k = \lambda_{max} / \lambda_{min}$. Generally if the condition number is less than 100, there is no serious problem with multicollinearity. However, if the condition number exceeds 1000, severe multicollinearity is indicated (Montgomery and Peck, 1982).

We employ the first two diagnostics in our study. When we achieve a correlation matrix, we first inspect correlation values ($|r_{ij}|$). If there is no correlation value that exceeds 0.95, we can analyze our model by using linear regression analysis. On the other hand, if we find one or more correlation values which exceed 0.95, we determine that multicollinearity exists in the model. The next problem is how we deal with multicollinearity.

2.2 Linear Regression Analysis

In order to deal with multicollinearity, we follow Montgomery and Peck's (1982) methods. They proposed three methods: (1) collecting additional data, (2) model respecification, and (3) ridge regression. The first method, collecting additional data, has been suggested as the best method. However, the additional data should be collected in a manner designed to breakup the multicollinearity in the data. Unfortunately, this method is not always possible because of economic constraints or because the process being studied is no longer available for sampling.

The second method, model respecification, is considered. Since multicollinearity is caused by two or more highly correlated regressors are used in the regression equation, some respecification of the equation may lessen the impact of multicollinearity. One approach is to *redefine the regressors*. For example, if X_1, X_2, and X_3 are nearly linearly dependent, it may be possible to find some function such as $X = X_1 + X_2 + X_3$ that preserves the information content in the original regressors but also reduces the multicollinearity. Another approach is *variable elimination*. For example, if X_1, X_2, and X_3 are nearly linearly dependent, eliminating one regressor (e.g., X_2) may be helpful. This approach is widely used and often a highly effective technique.

The third method, ridge regression, is a modified linear regression. When the method of least squares is applied to nonorthogonal data, the estimations of the regression coefficients are very poor. Ridge regression is developed in order to adjust the poor estimation. However, ridge regression is a controversial regression (Montgomery and Peck, 1982).

When we follow the first and/or the second methods, we can employ linear regression with our models. However, if we follow the third method, we will employ a modified linear regression, called ridge regression. We determine to follow the second method (*model respecification*) throughout our study because we can employ linear regression directly. Additionally, we will use *variable elimination* approach.

We understand that management uses this regression because linear regression can be interpreted easily. Additionally, ridge regression is a controversial regression when we find a biased value of the regression. Several authors have proposed procedures for choosing the biased value. There is no assurance that any method will produce the optimal biased value (Montgomery and Peck, 1982).

When we modify our model, we employ the linear regression with our model. We inspect our model to see whether multicollinearity exists by inspecting the VIFs. Fortunately, we can achieve the VIF of each independent variable by using SPSS. Therefore, we can modify our models back and forth. Once we find one or more of the VIFs which exceed 10, we can go back to modify a model. On the other hand, if there is no VIF exceeding 10 in a model, we assume that multicollinearity does not exist in the model.

One may question that if we take some variables out, can we prove some of our hypotheses? The answer is in our methodology. We will group variables which have a high relationship with each other. When we achieve a coefficient of the representative variable in the linear regression, the effect of other variables in the same group, to the dependent variable will be considered as the same direction and the same amount, as what a representative variable will do because of their relationships.

Therefore, we reconsider the correlation matrix. We find that a COMMIT1 variable has high correlation values with EXPER1 and REPUTE variables. One of these variables can represent the other variables because they have a high relationship with each other. We understand that most researchers are engineers and scientists and they conduct experiments. Additionally, most researchers need to publish in journals. It is possible that the total amount of papers has a high relationship with the amount of experimental papers and journals.

We use a COMMIT1 variable as a representative variable of these three variables (COMMIT1, EXPER1, and REPUTE). Therefore, our individual regression is modified. The new individual regression is shown in the equation (5.2).

$$PERSIST1 = \alpha_1 + \beta_1 COMMIT1 + \beta_2 NETWK1 + \beta_3 AREA1 + \beta_4 MTRL1 + \delta_1 \quad (5.2)$$

We then employ linear regression analysis with our model. The results are shown in Table 6.

Table 6 Coefficients of the Individual Regression

Variables	Beta	t	Sig.	VIF
COMMIT1	.027	3.178	.001	8.281
NETWK1	.127	22.357	.000	3.641
AREA1	.537	100.959	.000	3.177
MTRL1	.029	3.806	.000	6.598
Constant		12.640	.000	

Dependent variable: PERSIST1
An adjusted R-square: 0.473
N: 59,267 researchers

According to the equation (5.2), the linear regression of the individual persistence is shown in the equation (5.3).

$$\text{PERSIST1} = 0.000 + 0.027\ \text{COMMIT1} + 0.127\ \text{NETWK1} + 0.537\ \text{AREA1} + 0.029\ \text{MTRL1} \quad (5.3)$$

Since the COMMIT1, EXPER1, and REPUTE variables are in the same group, we can say that the effect of EXPER1 and REPUTE variables to the individual persistence (PERSIST1) are considered in the same direction and the same magnitude as the COMMIT1 does.

It should be noted that *reverse causality* may consider. There is possibility that the variable we are treating as "dependent" variable in this study may in fact be "independent" variable and could be used to predict variables that we are including as "independent." The persistence (PERSIST1) may affect the independent variables such as COMMIT1, NETWK1, EXPER1, AREA1, MRTL1, and REPUTE.

For example, it is possible that researchers who persist in the R&D community are likely to publish a greater amount of papers (COMMIT1). In order to publish papers, researchers must gain further knowledge, conduct experiments, write a paper, and submit to publishers. It is a time-consuming process. Basically, it takes about a year to publish one paper. Therefore, if researchers persist in the R&D community for many years, they are likely to publish a greater amount of papers.

It is possible that researchers who persist in the R&D community are likely to also have a greater numbers of co-authors (NETWK1). Most papers are published by many authors. Researchers need to know what fields of technology their co-authors are interested in. They also need to learn how to work together which also takes times. Therefore, if researchers persist in the R&D community many years, they are likely to have a greater amount of co-authors.

It is possible that researchers who persist in the R&D community are likely to have greater numbers of experimental work (EXPER1). Experiments, sometimes, need specific materials and tools or equipment. Researchers have to purchase new things or modify their old equipment. Furthermore, researchers need time to accumulate their knowledge. Finally, they need time to conduct their experiments. Therefore, if researchers persist in the R&D community many years, they are likely to have a great amount of experimental work.

It is possible that researchers who persist in the R&D community are also likely to have a greater numbers of research areas (AREA1). Although, researchers have a variety of ideas to conduct research, but they cannot conduct all of their ideas at once. This is in part due to budget or time constraints. Therefore, they conduct their research in limited research areas. Each research needs times. Therefore, if researchers persist in the R&D community, they are more likely to have a greater amount of research areas.

It is possible that researchers who persist in the R&D community are likely to have a greater amount of material-related papers (MTRL1). As discussed earlier, the semiconductor is a material basis technology. Sometimes, researchers need to use new composite materials in their research. They have to "make" new materials themselves. This process is usually a very time-consuming process. Therefore, if researchers persist in the R&D community, they are likely to have a greater amount of material-related papers.

Finally, it is possible that researchers who persist in the R&D community are likely to have a greater amount of journal papers (REPUTE). As discussed previously, to publish papers in journals take time. Researchers have to edit their papers perhaps several times to fit within editors' requirements. Basically, it takes about half year to a year to achieve the final, camera-ready article for publication or conference proceeding. Therefore, if researchers persist in the R&D community, they are likely to have a greater amount of journal papers.

However, these possibilities are not the interest or the focus in this study. We present these possibilities because some may argue about our findings and be interested in the reverse causality. We focus on which influential factors affect the persistence of members in the R&D community. Therefore, we will keep our frameworks and methodologies.

We interviewed some researchers who work in the semiconductor laser diode technology directly and indirectly. According to our interviews, researchers agree that the technological network and experimental work highly affect their persistence. They also agree that the research diversity, technological characteristics, sunk cost, and reputation factors affect their persistence moderately (see index for details).

We summarize that the amount of literature (COMMIT1), the amount of co-authors (NETWK1), the amount of experimental papers (EXPER1), the amount of research areas (AREA1), the amount of material related papers (MTRL1), and the amount of papers that are published in journals (REPUTE) affect the individual persistence significantly. Based on the results, the most influential factor is the amount of research areas. All hypotheses in the individual level are supported.

3. The Organizational Persistence

Consequently, we will study the persistence in the organizational level. As discussed earlier in section 3.6, we are focused on four interested factors: *(1) organization's commitment, (2) geographic location, (3) technological capability*, and *(4) organizational types*. We will also determine how to measure each factor in section 4.7.2. Table 7 summarizes how we measure each factor.

Table 7 Measurement of the Organizational Factors

Factors	Measurement
1. Organization's Commitment (TOTAL2)	1. the total amount of papers and patents that an organization contributes to the R&D community (papers)
2. Geographic Location (GEOGPH2)	2. the total number of papers and patents that is published by researchers in a country (papers)
3. Technological Capability (PATENT2)	3 the total amount of patents that is registered by any organization in a country (patents)
4. Organizational Types (FIRM, UNIV, and GOV)	4. the classification of an organization as either a firm, an academic institute, or a governmental laboratory

We will follow the individual persistence procedure. Therefore, we develop a regression equation based on the organizational hypotheses as shown in equation (5.4).

$$\text{PERSIST2} = \alpha_2 + \beta_7\text{TOTAL2} + \beta_8\text{GEOGPH2} + \beta_9\text{PATENT2} + \beta_{10}(\text{FIRM} + \text{UNIV} + \text{GOV}) + \delta_2 \qquad (5.4)$$

whereas:

α_2: a constant value

$\beta_7, \beta_8, \ldots, \beta_{10}$: coefficient value of each factor

δ_2 : an error value of the regression

PERSIST2: the organization persistence

TOTAL2: the organization's commitment factor

GEOGPH2: the geographical factor

PATENT2: the technological capability factor.

We explore our data set by using descriptive statistics. We find that there are 3,071 organizations in the semiconductor laser diode R&D community. Table 8 provides further details.

Table 8 Descriptive Statistics of the Semiconductor Laser Diode R&D Community: The Organization Level

Variables	Minimum	Maximum	Mean	Std. Deviation
PERSIT2	1	33	6.6799	7.9240
TOTAL2	1	2844	16.0788	82.6679
GEOGPH2	0	18778	8019.04	7658.42
PATENT2	0	243	.91	8.12
FIRM	0	1	.36	.48
UNIV	0	1	.45	.50
GOV	0	1	.19	.40

N: 3,071 organizations

In Table 8, we find that on average, an organization persists in the R&D community about 6.68 years and also contributes their knowledge to the semiconductor laser diode R&D community in about 16 papers. Additionally, on average, an organization has patented about 1 patent. The percentages of firms, universities, governmental laboratories that have contributed knowledge in the R&D community are 36%, 45%, and 19%, respectively.

3.1 Correlation Analysis

The correlation analysis is employed in order to test correlations among the dependent variable and independent variables in the equation (5.4). Table 9 provides specific detailed analysis.

Table 9 Correlations of the Organizational Persistence

	PERSIST2	TOTAL2	GEOGPH2	PATENT2	FIRM	UNIV	GOV
PERSIST2	1.000	.322*** (.000)	-.031* (.078)	.043** (.014)	-.201*** (.000)	.228*** (.000)	-.034* (.054)
TOTAL2		1.000	.033* (.062)	.512*** (.000)	-.009 (.592)	.018 (.300)	-.011 (.530)
GEOGPH2			1.000	.000 (.994)	.450*** (.000)	-.240*** (.000)	-.267*** (.000)
PATENT2				1.000	.009 (.590)	-.032* (.069)	.028 (.103)
FIRM					1.000	N/A	N/A
UNIV						1.000	N/A
GOV							1.000

***: Correlation is significant at the level 0.01 level (2-tailed)
**: Correlation is significant at the level 0.05 level (2-tailed)
*: Correlation is significant at the level 0.1 level (2-tailed)
N/A: not available
N: 3,071 organizations

In Table 9, the relationship between PERSIST2 and TOTAL2 is significant at the level of 0.01. It is shown that when an organization publishes more publications, it tends to have more persistence in the R&D community. Generally, an organization invests its time, manpower and financial supports to achieve advantage knowledge. Once the knowledge is achieved, the organization employs the knowledge in their business and receives some revenue. If an organization has a greater amount of publications, the organization will have greater advantage knowledge. Therefore, they can persist not only in the R&D community, but also in their business.

The relationship between PERSIST2 and GEOGPH2 is significant at the level of 0.1. However, the direction of the relationship is negative. It is shown that the amount of publications of an organization that are located in different geographic locations *contradicts* with the persistence of the organization. It is possible that universities, and governmental laboratories in some countries, e.g., developing countries, may publish a less amount of publications. However, their governments may support their research. Furthermore, some of their publications may be published in local journals.

The relationship between PERSIST2 and PATENT2 is positive and significant at the level of 0.05. It is shown that organizations that have greater amount of patent are more likely to persist in the R&D community. Basically, a patent is considered as an intellectual property, IP, of an organization. Most technology leading organizations, e.g., AT&T, Sony, and Toshiba, have a greater amount of patents.

We find that the relationship between PERSIST2 and FIRM2 is (–0.201). The relationship is in negative (-) direction significantly. Whereas, the relationship between PERSIST2 and UNIV, and GOV are 0.228 and (–0.34), respectively. This means that the persistence of the firm is less than the persistence of universities (0.228) and governmental laboratories (-0.034) significantly.

We understand that most firms focus on markets. A variety of technologies are employed and have been changed rapidly. Therefore, the persistence of firms should not be last. On the other hand, academic researchers and government researchers are likely to conduct their research because of their interests. According to this result, we will use a FIRM variable as a reference variable in the linear regression.

The relationship between TOTAL2 and GEOGPH2 is significant at the level of 0.1. It is shown that organizations that are located in a high knowledge density area tend to publish more publications. We understand that the organizations may take advantage from the "technology spillover" phenomenon. Their researchers may have a greater amount of technological networks.

We also find that the relationship between TOTAL2 and PATENT2 is significant at the level of 0.01. It is shown that an organization that has its technological capabilities tends to publish more publication. We understand that once new knowledge is patented, an organization is more comfortable with contributing their knowledge to the R&D community. Therefore, we may state that the more patents, the more publications an organization contributes.

The relationship between PERSIST2 and PATENT2 is significant at the level of 0.05. It is shown that an organization that has greater amount of patents is more likely to persist in the R&D community. As discussed earlier, a patent is an intellectual property. Organizations that have a great amount of patents can take advantage in their business. Therefore, they can survive in the business and also persist in the R&D community.

The relationships between GEOGPH2 and FIRM, UNIV, and GOV are significant at the level of 0.01. They are 0.450, (-0.240), and (–0.267), respectively. It is shown that the geographical location factor has a positive relationship with only the firms' location. On the other hand, the geographical location factor has *inverted* relationship with the universities' location and the governmental laboratories' location. Krugman (1991) states that a knowledge-intensive region relates to industrial firm clusters. This means that firms are likely to locate in a high knowledge density region. On the other hand, universities and governmental laboratories are supported by governments. The locations of these organizations are not necessary to locate in a high knowledge density region.

The relationship between PATENT2 and UNIV is significant at the level of 0.1. The relationship is negative. It is shown that universities are less likely to patent in the semiconductor laser diode R&D community significantly. We find that there are 259 organizations that have patented but only 37 universities (1.20% of 3,071 organizations) have patented. Most academic researchers conduct research because of their curiosity and knowledge. They may not intend to patent their knowledge as firm researchers need.

Finally, the relationship among FIRM, UNIV, and GOV are not provided because they are dummy variables which their values are either 1 or 0 in each record. Therefore, their relationships are not available.

According to our criterion value (a high correlation value that must exceed 0.95), we find that no correlation is considered as a high correlation value. The highest correlation value in Table 9 is the correlation between TOTAL2 and PATENT2. It is 0.512. However, the figure is lower than the criterion value.

3.2 Linear Regression Analysis

We employ the linear regression analysis directly with the regression equation (5.4). The results are shown in Table 10.

Table 10 Coefficients of the Organizational Regression

Variables	Beta	t	Sig.	VIF
TOTAL2	.334	18.666	.000	1.216
GEOGPH2	.080	4.444	.004	1.225
PATENT2	.052	2.877	.000	1.248
UNIV	.259	13.110	.000	1.480
GOV	.068	3.474	.001	1.468
Constant		11.161	.000	

Dependent variable: PERSIST2
An adjusted R-square: 0.193
N: 3,071 organizations

According to the results in the Table 10, the organizational persistence regression is shown in equation (5.5).

$$PERSIST2 = 0.000 + 0.334\,TOTAL2 + 0.080\,GEOGPH2 + 0.052\,PATENT2 + 0.259\,UNIV + 0.068\,GOV + \delta_2 \quad (5.5)$$

In Table 10, it is shown that the total amount of literature (TOTAL2), the geographical location (GEOGPH2), and the total amount of patents (PATEN2) are positively associated with the persistence of organization at the significant level of 0.01.

Additionally, the coefficients of UNIV and GOV are also positive. Since the UNIV and GOV variables are dummy variables, we interpret the effect of these variables in a different way.

We emphasize that we use a FIRM variable as the reference variable in the regression. Therefore, we compare the coefficients of dummy variables with a firm variable. The interpretation is that other thing being equal, universities and governmental laboratories have higher persistence of 0.259 and 0.068 times than that of firms, respectively, at the significant level of 0.01.

Although our hypotheses are supported in the organizational level, it should be noted that *reverse causality* may consider. For examples, it is possible that organizations which persist in the R&D community are likely to publish a great amount of papers (TOTAL2). Most organizations have specific targets to develop their technologies. They invest their resources such as money and people. However, it takes time to developed a new knowledge. Once they achieve their new knowledge, they usually document (patent) and contribute the new knowledge to an R&D community. Therefore, if organizations which persist in the R&D community, they are likely to publish a great amount of papers.

It is possible that organizations which persist in the R&D community are likely to located in the high density of knowledge areas (GEOGPH2). Organizations which have commitment to survive in their business, always search for better opportunities to take advantages from their environment. They look for better locations to achieve their goals. Therefore, if organizations which persist in the R&D community, they are likely to located in the high density of knowledge areas.

It is possible that organizations which persist in the R&D community are likely to have a great amount of patents (PATENT2). Organizations usually patent their new knowledge. As mentioned earlier, patent is the "intellectual" property. However, in order to achieve a new knowledge, organizations have to invest their times and other resources. They have to persist in specific fields of interest in specific R&D communities in order to accumulate knowledge. Therefore, if organizations which persist in the R&D community, they are likely to have a great amount of patents.

It is possible that organizations which persist in the R&D community are likely to be academic institutions. Academic institutions have specific characteristics. Most academic institutions are supported by their governments. Researchers in academic institutions can apply financial supports from the governments. They can persist in their interested fields as long as they need. Therefore, if organizations which persist in the R&D community, they are likely to be academic institutions.

As discussed earlier in the individual level, we present these possibilities because some ones may be interested in the reverse causality. However, we are interested in what influential factors affect the persistence of members of the R&D community. Therefore, we stick with our frameworks and methodologies.

Based on these results, we summarize that the amount of literature (TOTAL2), the geographical location (GEOGPH2), the amount of patent (PATENT2), and the types of organizations (FIRM, UNIV, and GOV) are affected to the organizational persistence significantly. All hypotheses in the organizational level are supported.

Malerba, et al. (1997) state that persistence is strongly related to the pattern of innovative activities. According to our findings, we find that universities and governmental laboratories have higher persistence than firms have significantly. This means that universities and governmental laboratories are good resources that firms can work with.

Tid and Trewhella (1997) state that universities are the most widely used external source of knowledge acquisition. They illustrate that pharmaceutical and biotechnology industries use universities as a critical source of innovation. In the semiconductor laser diode technology, universities and governmental laboratories are potentially good sources of innovations.

4. The National Persistence

Finally, we study the persistence at the national level. As discussed earlier in section 3.8, we will focus on five interesting factors: (1) *knowledge prerequisites,* (2) *manpower,* (3) *knowledge diversity,* (4) *technological infrastructure*, and (5) *sociocultural tendency.* We also determine how we measure each factor in section 7.3 of chapter III. Table 11 summarizes how we measure each factor.

Table 11 Measurement of the National Factors

Factors	Measurement
1. Technology Prerequisite (TOTAL3)	1. the total amount of papers and patents that researchers and/or organizations in each country contributes to the R&D community (papers)
2. Manpower(MPOWER3)	2. the total number of researchers in each country (persons)
3. Knowledge Diversity(AREA3)	3. the total amount of areas that is contributed by researchers and/or organizations in each country (areas)
4. Technological Infrastructure (ORG3)	4. the total amount of organizations in each country (organizations)
5. Sociocultural Tendency (CULTURE)	5. an average of the total number of areas of the published papers divided by the total number of researchers in each country (areas/researcher)

We follow the individual persistence procedure. We have developed a regression equation based on the national hypotheses. The equation is shown in equation (5.6).

$$\text{PERSIST3} = \alpha_3 + \beta_{11}\text{TOTAL3} + \beta_{12}\,\text{MPOWER3} + \beta_{13}\,\text{AREA3} + \beta_{14}\,\text{ORG3} + {} + \beta_{15}\,\text{CULTURE} + \delta_3 \qquad (5.6)$$

whereas:

α_3 : a constant value

$\beta_{11}, \beta_{12}, \ldots, \beta_{15}$: coefficient value of each factor

δ_3: an error value of the regression

PERSIST3: the national persistence

TOTAL3: the knowledge prerequisite factor

MPOWER3: the manpower factor

AREA3: the knowledge diversity factor

ORG3: the technological infrastructure factor

CULTURE: the sociocultural tendency factor

We explore our data set by using descriptive statistics. We find that there are 66 countries in the semiconductor laser diode R&D community. Table 12 provides more details.

Table 12 Descriptive Statistics of the Semiconductor Laser Diode R&D Community: The National Level

Variables	Minimum	Maximum	Mean	Std. Deviation
PERSIT3	1	33	17.76	11.17
TOTAL3	1	17621	748.29	2522.18
MPOWER3	1	18840	897.17	2644.60
AREA3	1	1507	220.12	306.23
ORG3	1	922	46.58	129.66
CULTURE	.25	10	1.8519	1.2842

N: 66 countries

In Table 12, we find that a country persists in the semiconductor laser diode R&D community about 17 years, contributes 748 papers and 220 relevant research areas on average. The average amount of organizations is 47 organizations. We also find that, on average, a researcher has proposed 1.85 research areas in each country. The US has the largest amount of researchers (18,840 researchers, 31.78% of the R&D community) and who have contributed 17,621 papers (34.80% of the R&D community) to the R&D community.

4.1 Correlation Analysis

We also employ the correlation analysis in this unit of analysis in order to test the relationships among the dependent variable and independent variables in equation (5.6). The details follow in Table 13.

Table 13 Correlations of the National Persistence

	PERSIST3	TOTAL3	MPOWER3	AREA3	ORG3	CULTURE
PERSIST3	1.000	.360*** (.003)	.390*** (.001)	.666** (.014)	.398*** (.001)	-.356*** (.003)
TOTAL3		1.000	.976*** (.000)	.820*** (.000)	.974*** (.000)	-.199 (.109)
MPOWER3			1.000	.858*** (.000)	.997*** (.000)	-.219* (.077)
AREA3				1.000	.859*** (.000)	-.290** (.018)
ORG3					1.000	-.218* (.078)
CULTURE						1.000

***: Correlation is significant at the level 0.01 level (2-tailed)
**: Correlation is significant at the level 0.05 level (2-tailed)
*: Correlation is significant at the level 0.1 level (2-tailed)
N: 66 countries

In Table 13, we find that the relationships among PERSIST3 and TOTAL3, MPWER3, AREA3, ORG3 are positive significantly at the level of 0.01. Based on the results of the correlation analysis, our hypotheses H11, H12, H13, and H14 are supported individually. However, the relationship between PERSIST3 and CULTURE is negative significantly. This means that the result *contradicts* our hypothesis (H15).

We find that the relationship between PERSIST3 and CULTURE is -0.356. We explore that there are 33 countries that have persisted in the semiconductor laser diode R&D community equal to or more than 20 years. These countries are technology leading countries such as the US, Japan, the UK, Germany, and France. The mean of the CULTURE variable of these countries is only 1.4389.

In technology leading countries, researchers may propose a variety of ideas. Due to a limitation of resources such as time and financial support for each project, they may confine their research within a limited amount of research areas. They may conduct new research areas in later projects. Additionally, they may need to conduct many experiments. Therefore, researchers conduct research within a specific amount of research areas. Based on this result, we summarize that our hypothesis (H15) is *contradicted.*

We find that every variable is significant at the level of 0.01 for all comparisons with PERSIST3. This is a significant exploration because when developing the hypotheses, we believed that it should be very positive. Furthermore, there are other significant findings which we will discuss now.

We find that the relationships among TOTAL3 and MPWER3, AREA3, and ORG3 are positive significantly at the level of 0.01. This means that a country which has a greater amount of researchers, research areas, and organizations is most likely to publish more publications. However, the relationship between TOTAL3 and CULTURE is negative and not significant.

We find that the relationship between MPOWER3 and AREA3 is positive significantly at the level of 0.01. This means that countries that have a greater number of research areas are more likely to have a greater number of researchers. Researchers have limited areas of knowledge. Therefore, countries that have a greater amount of research areas are more likely to have a greater amount of researchers.

We find that the relationship between MPOWER3 and ORG3 is positive significantly at the level of 0.01. Therefore, countries that have a greater number of organizations are more likely to have a greater number of researchers. Because management tends to provide equipment, resources and benefits in order to convince researchers to work, researchers are more likely to work within a good facility in a good region and with benefits.

However, the relationship between MPOWER3 and CULTURE is negative and significant at the level of 0.1. This shows that countries that have the greater sociocultural tendency factor are less likely to have the greater amount of researchers. We explore that most technology-oriented leading countries have the greatest amount of researchers.

We find that the relationship among AREA3 and ORG3 is positive significantly at the level of 0.01. This means that a country that has the greater amount of organizations is more likely to have the greater amount of research areas. In organizations, researchers work in different areas. Therefore, it is possible that a country that has a greater amount of organizations is also more likely to have a greater amount of research areas.

The relationship between AREA3 and CULTURE is negative and significant at the level of 0.05. As discussed earlier, though most technology leading countries have the greater amount of research areas, yet they have lower figures of sociocultural tendency value. On the other hand, the rest have higher figures of sociocultural tendency values and lesser amount of research areas. Therefore, the relationship is inverted.

We find that the relationship among ORG3 and CULTURE is negative and significant at the level of 0.1. As mentioned previously, most technology leading countries, which have the greater amount of organizations but have the lower figures of sociocultural tendency values. On the other hand, the rest have higher figures of sociocultural tendency values and a lesser amount of organizations. Therefore, the relationship is inverted.

We find that the correlation values among the independent variables are high in Table 13. For example, the correlation values between TOTAL3 and MPOWER3 and ORG3 are 0.976, and 0.974, respectively. We, therefore, assume that multicollinearity exists in the national persistence regression. We cannot employ the linear regression analysis with the regression directly.

4.2 Factor Analysis

In the Correlation matrix (Table 13), we consider that TOTAL3, MPOWER3, and ORG3 variables have a very high relationship with each other. It is possible that countries which have a greater amount of researchers and organizations may publish a greater amount of papers. We also notice the relationships among AREA3 with TOTAL3, MPOWER3, and ORG3 are quite consistent (0.820, 0.858, and 0.859, respectively). It is possible that AREA3 may be in the same group as these variables.

We employ factor analysis in order to inspect whether AREA3 is in the same group with TOTAL3, MPOWER3, and ORG3. The result shows that AREA3 should be in the same group with TOTAL3, MPOWER3, and ORG3. The reliability of this group (alpha value) is good (0.7453). Table 14 offers the results of comparisons.

Table 14: Results of Factor Analysis in National Persistence Model

Variables	Factor
TOTAL3	.96978
MPOWER3	.98638
AREA3	.91430
ORG3	.98616
CULTURE	-.31528

Alpha value of TOTAL3, MPOWER3, AREA3, and ORG3: .7453

According to the results of factor analysis, we have to combine four variables (TOTAL3, MPOWER3, AREA3 and ORG3) into one variable. The technology prerequisite, the manpower, the knowledge diversity, and the technological infrastructure may be consider as an environment that enhances researchers/organizations to conduct research and to persist in the R&D community. We may call this environment "productivity environment." Therefore, a new variable that combines the four variables will be called PROD3.

It is difficult to combine four variables (TOTAL3, MPOWER3, AREA3 and ORG3) which have different units of measurement into one. We determine to transform four units of measurement to Z-scores. To calculate a value of PROD3, we sum the four Z-scores and divide by four. Therefore, the value of PROD3 is changed to Z-score.

Furthermore, we also change the data of PERSIST3 and CULTURE variables into Z-scores. The modified national persistence is shown in equation (5.7).

$$ZPERSIST3 = \alpha_3 + \beta_{11}\ ZPROD3 + \beta_{12}\ ZCULTURE + +\delta_3 \qquad (5.7)$$

whereas:

α_3 : a constant value

β_{11}, β_{12}, β_{13} : coefficient value of each factor

δ_3 : an error value of the regression

ZPERSIST3: the nation persistence (Z-score)

ZPROD3 : the productivity environment factor (Z-score)

ZCULTURE : the sociocultural tendency factor (Z-score)

We will employ correlation regression analysis with the new national model. Table 15 provides the results of this analysis.

Table 15 Correlations of the Modified National Persistence Model

	ZPERSIST3	ZPROD3	ZCULTURE
ZPERSIST3	1.000	.469*** (.000)	-.356*** (.003)
ZPROD3		1.000	-.259* (.053)
ZCULTURE			1.000

***: Correlation is significant at the level 0.01 level (2-tailed)
*: Correlation is significant at the level 0.1 level (2-tailed)
N: 66 countries

In Table 15, the relationship between ZPERSIST3 and ZPROD3 is a positive direction and significant at the level of 0.01. This means that countries which have the greater amount of the productivity environment factor (the greater amount of publications, researchers, research areas, and/or organizations) are more likely to persist in the R&D community.

Our finding is supported by Patel and Pavitt's (1997) study. They state that to get technological change, there are two resources: (1) the skills, knowledge, and institutions that make up a country's capacity to generate and manage change, and (2) the capital goods, knowledge, and labor skill required to produce industrial good.

The relationship between ZPERSIST3 and ZCULTURE is a negative direction and significant at the level of 0.01. As discussed previously, we modified the two variables into Z-scores. However, the relationship between these variables (PERSIST3 and CULTURE) is the same.

We also find that the relationship between ZPROD3 and CULTUTRE is a negative direction and significant at the level of 0.1. This means that countries which have a higher amount of sociocultural tendency values are less likely to have a greater amount of publications, researchers, research areas, and organizations. We find that most technology leading countries have the greater amount of publications, researchers, research areas, and organizations, but they have low figures of the sociocultural tendency values.

4.3. Linear Regression Analysis

In order to test our model, we employ linear regression analysis with the modified national persistence model (equation (5.7). The results are shown in Table 16.

Table 16 Coefficients of the Modified National Regression

Variables	Beta	t	Sig.	VIF
ZPROD3	.407	3.704	.000	1.061
ZCULTURE	-.258	-2.349	.022	1.061
Constant		.000	1.000	

Dependent variable: ZPERSIST3
An adjusted R-square: 0.260
N: 66 nations

According to the equation (5.7), the regression of the national persistence is shown in equation (5.8).

$$ZPERSIST3 = 0.000 + 0.407\ ZPROD3 - 0.258\ ZCULTURE \qquad (5.8)$$

In equation (5.8), it is shown that countries that have the greater amount of publications, researchers, research areas, and organizations are more likely to persist in the R&D community at a significant level of 0.01. Although we cannot prove hypotheses H11, H12, H13, and H14 individually because we combined them together, the combination of these variables still affects the national persistence significantly.

On the other hand, countries that have the greater value of sociocultural tendency are less likely to persist in the R&D community at significant level of 0.1. This means that our hypothesis (H15) is contradicted.

According to our research question at the national level, we find that the productivity environment factor, which includes the technological prerequisite, the manpower, the knowledge diversity, and the technological infrastructure factors, affects the national persistency in a positive direction significantly. On the other hand, the sociocultural tendency factor of the nation affects the national persistence in the negative direction significantly.

5. Conclusions

Part 1 of this dissertation attempted to test six hypotheses derived from our framework, an individual persistence framework, as shown in Figure 10. The individual framework was based on the assumption that a researcher has persisted in the R&D community because of his/her investment (sunk cost), co-authors (technological networks), experimental papers (experimental work), research areas (research diversity), technological characteristics, and journal papers (reputation).

Based on our individual model, there is multicollinearity. We found that the amount of papers (sunk cost), the amount of experimental papers (experimental work), and the amount of journal papers (reputation) have a very high relationship with each other, therefore, we group them together. Thus, we choose the amount of papers (sunk cost) as a representative factor to put in the linear regression.

We found that the sunk cost (which includes the experimental work and the reputation approaches), the technological network, the research diversity, and the technological characteristics approaches are supported significantly. Furthermore, we find that the *research area* factor is the most influential factor affecting the individual persistency.

Part 2 of this dissertation attempted to test four hypotheses derived from our framework, an organizational persistence framework, as shown previously in Figure 11. The organizational persistence framework was based on the assumption that an organization has persisted in the R&D community because of its commitment (organization's commitment), location (geographic location), patents (technological capability), and types of organization.

All hypotheses are supported by significant statistical results. This means that the organization's commitment, geographic location, technological capability, and the types of organization affect the organizational persistence. The most influential factor is the organization's commitment.

Part 3 of this dissertation attempted to test five hypotheses derived from our framework, a national persistence framework, as illustrated in Figure 12. The national persistence framework was based on the assumption that a nation has persisted in the R&D community because of its total amount of papers (technological prerequisites), researchers (manpower), total amount of research areas (knowledge diversity), total amount of organizations (technological infrastructure), and its national work value (sociocultural tendency).

There is multicollinearity in the national persistence model. We find that the total a mount of publications (TOTAL3), the manpower (MPOWER3), the knowledge diversity (AREA3), and the amount of organization (ORG3) factors have a high relationship with each other. Therefore, we group them together. Furthermore, we combine these factors into a productivity environment (PROD3) factor.

Based on our findings, the productivity environment (PROD3) affects the national persistence positively. On the other hand, and the sociocultural tendency factors affects the national persistence negatively.

CHAPTER VI

THE SEMICONDUCTOR LASER DIODE R&D COMMUNITY IN JAPAN AND THE UNITED STATES

It is known that Japan and the US are leading technology countries, especially in the electronic industry. In the semiconductor laser diode R&D community, both countries are leaders. Figure 22 shows the trends of the shares of publications by researchers in Japan, the US, and the others. In the total of 49,250 papers from 1966 to 1998, the Japanese share is 19.31% and the US share is 35.68%. It is observed that the US researchers dominated the first stage of the technology development, and that other countries stabilized more or less in the early 1980's, but they show small increase in the mid-1990's to present.

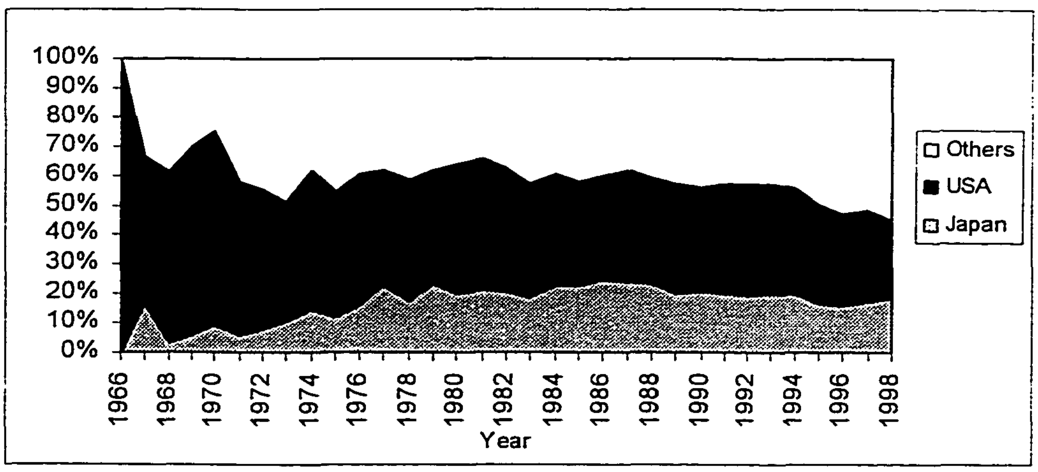


Figure 22 Share of the Semiconductor Laser Diode R&D Community (1966-1998)

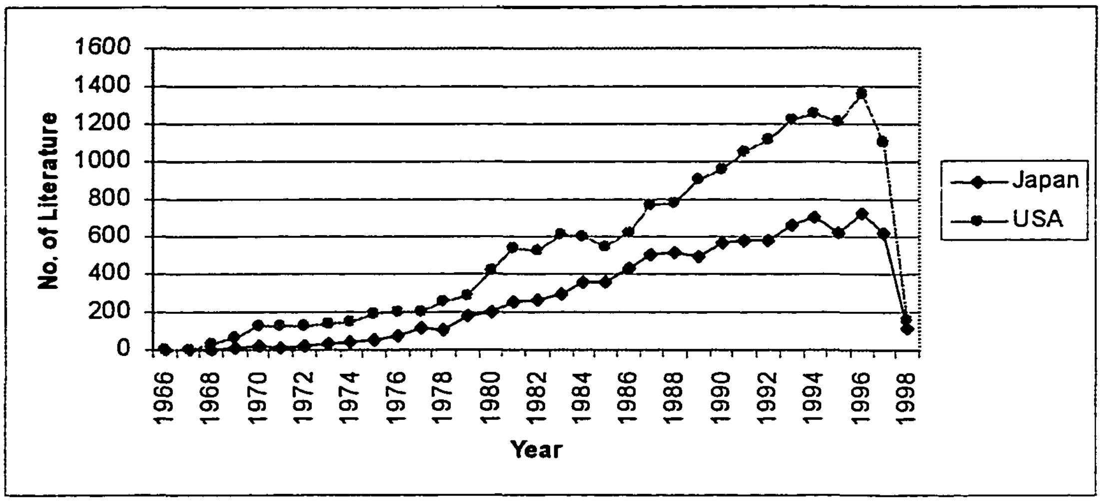


Figure 23 Trends of Publications of Japan and the US R&D Community (1966-1998)

Figure 23 shows trends of publications by researchers in Japan and the US from 1966 to 1998. The trends of both countries are similar to the trend of the semiconductor laser diode R&D community. They gradually increase until reaching their highest point in 1996, and they began declining in the last two years.

Since Japan and the United States are major players in the semiconductor laser diode R&D community, it is interesting to study their semiconductor laser diode R&D communities. We classify our comparison study into three units of analysis. They are individual, organization, and firm levels. Each level is studied.

1. The Individual Persistence

We will first examine our data set roughly. We find that there are 6,749 Japanese researchers and 18,840 US researchers in the R&D communities. The Japanese and the US researchers comprise about 43% of researchers in the semiconductor laser diode R&D

community. A Japanese researcher has contributed his/her knowledge to the R&D community about 4.9 years on average. On the other side, a US researcher has contributed about 2.99 years on average. However, the standard deviation of the Japanese R&D community is higher than the US R&D community. Table 17 provides more details regarding our findings.

Table 17: Descriptive Statistics of the Japanese and the US Semiconductor Laser Diode R&D Communities: The Individual Level

Variables	Country	Minimum	Maximum	Mean	Std. Deviation
PERS1	Japan	1	31	4.90	5.93
	US	1	31	2.99	4.11
TOTAL1	Japan	1	246	5.42	11.15
	US	1	305	3.41	9.00
NETWK1	Japan	0	161	10.80	14.61
	US	0	251	8.08	11.72
EXPER1	Japan	0	188	4.49	9.18
	US	0	240	2.75	7.39
AREA1	Japan	0	159	13.03	14.28
	US	0	122	9.53	9.56
MTRL1	Japan	0	187	3.47	7.76
	US	0	253	2.15	6.19
REPUTE	Japan	0	180	3.68	8.16
	US	0	251	2.00	6.57

N(Japan): 6,749 researchers
N(the US): 18,840 researchers

In Table 17, we observe that, on average, a Japanese researcher has higher performance than the US researcher in all variables. The standard deviations of a Japanese researcher is also higher than US researcher in all variables. We find that the US R&D community has higher performance than the Japanese R&D community in the maximum column in most variables, except PERS1 and AREA1.

We find that a Japanese researcher has persisted 4.9 years in the R&D community and contributed 5.42 papers, 13.03 research areas, and has had 10.80 co-authors on average. The Japanese researcher also has contributed 4.49 (82.84% of 5.42 papers) experimental papers, and 3.47 (64.02% of 5.42 papers) material-related papers. Finally, a Japanese researcher has published 3.68 (67.89% of 5.42 papers) papers in journals on average.

On the other hand, the US researcher has persisted 2.99 years in the R&D community and contributed 3.41 papers, 9.53 research areas, and has had 8.08 co-authors on average. The US researcher also has contributed 2.75 (80.64% of 3.41 papers) experimental papers, and 2.15 (63.04% of 3.41 papers) material-related papers. Finally, the US researcher has published 2.00 (58.65% of 3.41 papers) papers in journals on average.

Although the Japanese researchers and the US researchers have different performance in the semiconductor laser diode R&D community on average, the percentages of factors that we consider are almost the same. This means that the characteristics of researchers of both countries are alike.

1.1 The F-Test and T-Test of The Japanese and the US R&D Communities

We employ a t-test technique in order to know whether the means of variables of the Japanese and the US researchers are the same. Furthermore, we also employ the F-test in order to know whether the variances of variables of the Japanese and the US researchers are the same. We set a null hypothesis of t-test that the means of variables of the Japanese and the US researchers are the same. We also set a null hypothesis of t-test that the means of variables of the Japanese and the US researchers are the same. Table 18 provides results of the variables explored.

Table 18: Independent Sample Test of the Japanese and the US Semiconductor Laser Diode R&D Communities: The Individual Level

Variables	F-test		t-test	
	F	Sig.	t	Sig.(two –tailed)
PERSIST1	1716.849	.000	28.894	.000
COMMIT1	375.054	.000	14.742	.000
NETWK1	271.947	.000	15.259	.000
EXPER1	397.023	.000	15.448	.000
AREA1	817.316	.000	22.379	.000
MTRL1	359.547	.000	13.927	.000
REPUTE	425.849	.000	16.820	.000

N(Japan): 6,749 researchers
N(the US): 18,840 researchers

In Table 18, we find that the significant values of all variables of the Japanese and the US researchers in both of the F-test and the t-test are 0.001. This means we can reject the null hypotheses. Based on our analysis, we can say that the variances and means of all variables of the Japanese and the US researchers are different at the significant level of 0.01.

In the Japanese and the US R&D communities, we find that they have contributed almost 30,000 papers (29,860 papers (academic papers, conference proceeding, and patents)) from 1966 to 1998. We follow the individual model in section 5.2 but specify the data only for Japan and US. Equations (6.1) and (6.2) show the Japanese and US R&D community models, respectively.

$$JPERS1 = \alpha_1 + \beta_1 JCOMMIT1 + \beta_2 JNETWK1 + \beta_3 JEXPER1 + \beta_4 JAREA1 + \beta_5 JMTRL1 + \beta_6 JREPUTE1 + \delta_1 \quad (6.1)$$

$$USPERS1 = \alpha_1 + \beta_1 UCOMMIT1 + \beta_2 UNETWK1 + \beta_3 UEXPER1 + \beta_4 UAREA1 + \beta_5 UMTRL1 + \beta_6 UREPUTE1 + \delta_1 \quad (6.2)$$

whereas:

α_1: a constant value

$\beta_1, \beta_2, \ldots, \beta_6$: coefficient value of each factor

δ_1: an error value of the regression

JPERS1 and UPERS1: the individual persistence of the Japanese and the US R&D communities, respectively

JCOMMIT1 and UCOMMIT1: the sunk cost factor of the Japanese and the US R&D communities, respectively

JNETWK1 and UNETWK1: the technological network factor of the Japanese and the US R&D communities, respectively

JEXPER1 and JEXPER1: the experimental work factor of the Japanese and the US R&D communities, respectively

JAREA1 and UAREA1: the research diversity factor of the Japanese and the US R&D communities, respectively

JMTRL1 and JMTRL1: the technological characteristic factor of the Japanese and the US R&D communities, respectively

JREPUTE1 and UREPUTE1: the reputation factor of the Japanese and the US R&D communities, respectively

1.2 Correlation Analysis of the Japanese R&D Community: The Individual Level

We employ the correlation analysis in order to test the relationship among a dependent variable and independent variables. First, the Japanese R&D community is tested. The result is shown in Table 19.

Table 19: Correlations of the Japanese R&D Community: The Individual Level

	JPERS2	JCOMMIT1	JNETWK1	JEXPER1	JAREA1	JMTRL1	JREPUTE1
JPERS1	1.000	0.634*** (.000)	0.678*** (.000)	0.629*** (.000)	0.740*** (.000)	0.593*** (.000)	0.611*** (.000)
JCOMMIT1		1.000	0.861*** (.000)	0.988*** (.000)	0.838*** (.000)	0.937*** (.000)	0.981*** (.000)
JNETWK1			1.000	0.862*** (.000)	0.873*** (.000)	0.794*** (.000)	0.818*** (.000)
JEXPER1				1.000	0.850*** (.000)	0.932*** (.000)	0.967*** (.000)
JAREA1					1.000	0.778*** (.000)	0.798*** (.000)
JMTRL1						1.000	0.915*** (.000)
REPUTE4							1.000

***. Correlation is significant at the level of 0.01 (2-tailed)
N: 6,749 records

In Table 19, we find that the relationship among the dependent and the independent variables are in a positive direction. Additionally, all of them are significant at the level of 0.01. This means that our hypotheses are applicable with the Japanese researchers. We also find some significant relationship among the independent variables.

The relationships among JCOMMIT1 and JNWETWK1, JEXPER1, JAREA1, JMTRL1, and JREPUTE1 are positive and significant at the level of 0.01. It is shown that a Japanese researcher who has the greater amount of co-authors, experimental papers, research areas, material related papers, or journal papers is like to publish more publication.

The relationships among JNWETWK1 and JEXPER1, JAREA1, JMTRL1, and JREPUTE1 are positive and significant at the level of 0.01. It is shown that a Japanese researcher who has the greater amount of experimental papers, research areas, material related papers, or journal papers is more likely to have the greater amount of co-authors.

The relationships among JEXPER1 and JAREA1, JMTRL1, and JREPUTE1 are positive and significant at the level of 0.01. It is shown that a Japanese researcher who has the greater amount of research areas, material related papers, and/or journal papers is likely to have the greater amount of experimental papers.

The relationship among JAREA1 and JMTRL1, and JREPUTE1 are positively and significant at the level of 0.01. It is shown that a Japanese researcher who has the greater amount of material related papers, or journal papers is like to have the greater amount of research areas.

Finally, the relationship among JMTRL1, and JREPUTE1 is positive and significant at the level of 0.01. Therefore, Japanese researchers who have a greater amount of journal papers is more likely to have the greater amount of material related papers.

Based on our correlation criterion value ($|r_{ij}| > 0.95$), we find higher correlation values among independent variables. They are 0.988 (JCOMMIT1 and JEXPER1), 0.981 (JCOMMIT1 and JREPUTE), and 0.967 (JEXPER1 and JREPUTE). Therefore, we consider that multicollinearity exists in the Japanese researcher regression.

As discussed in the descriptive statistics of the Japanese researchers, the percentages of experimental papers and papers that published in journals of a Japanese researcher to the total amount of papers that he/she has contributed are high. The relationship among them are clearly revealed.

1.3 The Linear Regression Analysis of the Japanese and the US R&D Communities

We cannot employ the linear regression analysis with the Japanese individual regression directly because of multicollinearity, therefore, we must modify our model. We observe that JCOMMIT1, JEXPER1, and JREPUTE variables have a high relationship with each other. We determine to choose JCOMMIT1 as a representative variable of these variables. Therefore, the equation (6.1) is modified. The new regression of Japanese researchers of the semiconductor laser diode R&D community is shown in equation (6.3).

$$JPERS1 = \alpha_1 + \beta_1 JCOMMIT1 + \beta_2 JNETWK1 + \beta_3 JAREA1 + \beta_4 JMTRL1 + \delta_1 \qquad (6.3)$$

We employ the linear regression analysis with the model. The results are given in Table 20.

Table 20: Coefficients of the Japanese R&D Community: The Individual Level

Variables	Beta	t	Sig.	VIF
JCOMMIT1	-.058	-2.053	.040	12.218
JNETWK1	.144	7.523	.000	5.503
JAREA1	.629	35.332	.000	4.775
JMTRL1	.044	1.903	.000	8.200
Constant		13.091	.000	

Dependent variable: JPERS1
An adjusted R-square: 0.552
N: 6,749 researchers

In Table 20, we find that a VIF of JCOMMIT1 exceeds 10 that we have set as a critical value. This means that multicollinearity still exists in the model. Therefore, we have to modify our model again. Since we know that a JCOMMIT1 may cause multicollinearity, we take this variable out. According to our methodology, we choose a JCOMMIT1 from a group of three variables (JCOMMIT1, JEXPER1, and JREPUTE). We find another representative variable of the group.

First, we put a JEXPER1 variable instead of a JCOMMIT1 variable in equation (6.3). We employ correlation analysis with the model. The maximum correlation value in the correlation matrix is 0.942. It is not a high correlation value. Therefore, we employ the linear regression analysis with the model. Unfortunately, we find that a VIF of JEXPER1 is 14.140. This means that multicollinearity exists in the model.

Second, we put a JREPUTE variable instead of a JEXPER1 variable in equation (6.3). We employ correlation analysis with the model. The maximum correlation value in the correlation matrix is 0.818. It is not a high correlation value. Therefore, we employ the linear regression analysis with the model. Fortunately, we find that no VIF of the model exceeds 10. We assume that multicollinearity does not exist in the model. The final modified regression is illustrated in the equation (6.4).

$$JPERS1 = \alpha_1 + \beta_1 JNETWK1 + \beta_2 JAREA1 + \beta_3 JMTRL1 + \beta_4 JREPUTE + \delta_1 \quad (6.4)$$

We employ the linear regression analysis one more time. The result is shown in Table 21.

Table 21: Revised Coefficients of the Japanese R&D Community: The Individual Regression

Variables	Beta	t	Sig.	VIF
JNETWK1	.127	6.890	.000	5.100
JAREA1	.619	35.237	.000	4.650
JMTRL1	-.009	-.417	.667	6.430
JREPUTE	.021	.967	.334	7.250
Constant		13.865	.000	

Dependent variable: JPERS1
An adjusted R-square: 0.552
N: 6,749 researchers

According to the results in the Table 21, the persistence of Japanese researchers of the semiconductor laser diode R&D community is illustrated in the equation (6.5).

$$JPERS1 = 0.000 + 0.127\ JNETWK1 + 0.619\ JAREA1 - 0.009\ JMTRL + 0.021\ JREPUTE \quad (6.5)$$

Equation (6.5) illustrates that the technological network (JNETWK1) and the research diversity (JAREA1) approaches of the Japanese individual model are supported at the significant level of 0.01. However, the total amount of material related papers (JMTRL1) and the journal papers (JREPUTE) that are published by a Japanese researcher do not affect his/her persistence significantly.

It is important to emphasize that a JREPUTE variable is a representative variable of the three variables (JTOTAL1, JEXPER1, and JREPUTE). Additionally, their correlation values are in the same direction (positive sign). Therefore, we can interpret the effect of JTOTAL1 and JEXPER1 as a JREPUTE variable does.

6.1.4 Correlation Analysis of the US R&D Community: The Individual Level

The US semiconductor laser diode R&D community is tested and the correlation analysis is employed, as shown in Table 22.

Table 22: Correlations of the US R&D Community: The Individual Level

	USPER1	COMMIT4	NETWK4	EXPER4	AREA4	MTRL4	REPUTE4
USPER1	1.000	0.525*** (.000)	0.569*** (.000)	0.515*** (.000)	0.675*** (.000)	0.516*** (.000)	0.481*** (.000)
COMMIT4		1.000	0.818*** (.000)	0.982*** (.000)	0.763*** (.000)	0.942*** (.000)	0.974*** (.000)
NETWK4			1.000	0.832*** (.000)	0.796*** (.000)	0.774*** (.000)	0.762*** (.000)
EXPER4				1.000	0.774*** (.000)	0.950*** (.000)	0.952*** (.000)
AREA4					1.000	0.738*** (.000)	0.684*** (.000)
MTRL4						1.000	0.914*** (.000)
REPUTE4							1.000

***. Correlation is significant at the level of 0.01 (2-tailed)
N: 18,840 researchers

In Table 22, we find that the relationship among the dependent and the independent variables are in a positive direction. Additionally, all of them are significant at the level of 0.01. This means that our hypotheses are also applicable with US researchers. We also find some significant relationships among the independent variables.

The relationships among UCOMMIT1 and UNWETWK1, UEXPER1, UAREA1, UMTRL1, and UREPUTE1 are positive and significant at the level of 0.01. It is shown that the US researcher who has the greater amount of co-authors, experimental papers, research areas, material related papers, or journal papers is more likely to publish more publications.

The relationships among UNWETWK1 and UEXPER1, UAREA1, UMTRL1, and UREPUTE1 are positively and significant at the level of 0.01. It is shown that the US researchers who have the greater amount of experimental papers, research areas, material related papers, or journal papers are also likely to have the greater amount of co-authors.

The relationships among UEXPER1 and UAREA1, UMTRL1, and UREPUTE1 are positively and significant at the level of 0.01. Therefore, the US researchers who have the greater amount of research areas, material related papers, or journal papers are more likely to have the greater amount of experimental papers.

The relationship among UAREA1 and UMTRL1, and UREPUTE1 are positively and significant at the level of 0.01. This shows that the US researchers who have the greater amount of material related papers or journal papers are more likely to have the greater amount of research areas as well.

Finally, the relationship among UMTRL1, and UREPUTE1 is positive and significant at the level of 0.01. Therefore, it is shown that the US researchers who have the greater amount of journal papers are more likely to have the greater amount of material related papers.

In Table 22, we find high correlation values ($|r_{ij}| > 0.95$) among independent variables. They are 0.982 (UCOMMIT1 and UEXPER1), 0.974 (UCOMMIT1 and UREPUTE), and 0.952 (UEXPER1 and UREPUTE). Therefore, we assume that there is multicollinearity in the model.

1.5 The Linear Regression Analysis of the US R&D Community:

The Individual Level

We will further modify the regression that is illustrated in equation (6.2). We notice that UCOMMIT1, UEXPER1, and UREPUTE variables have a high relationship with each other. We choose a UCOMMIT1 variable as a representative variable of these variables. The modified regression is shown in the equation (6.6).

$$UPERS1 = \alpha_I + \beta_I UCOMMIT1 + \beta_2 UNETWK1 + \beta_3 UAREA1 + \beta_4 UMTRL1 + \delta_I \quad (6.6)$$

We employ the linear regression analysis with the model as Table 23 illustrates.

Table 23: Coefficients of the US R&D Community: The Individual Regression

Variables	Beta	t	Sig.	VIF
UCOMMIT1	-.102	-5.814	.000	10.805
UNETWK1	.102	9.731	.000	3.844
UAREA1	.612	65.146	.000	3.073
UMTRL1	.082	5.148	.000	8.892
Constant		7.002	.000	

Dependent variable: UPERS1
An adjusted R-square: 0.460
N: 11,840 researchers

In Table 23, we find that a VIF of UCOMMIT1 is 10.805. It exceeds the critical value (VIF > 10) that we have set. This means that multicollinearity exists in the model. Therefore, we have to modify our model again. Since we know that the UCOMMIT1 variable may cause multicollinearity, we remove this variable out. According to our methodology, we choose the UCOMMIT1 from a group of three variables (UCOMMIT1, UEXPER1, and UREPUTE). We will do the same procedure that we did in the Japanese researcher R&D community.

First, we put the UEXPER1 variable instead of the UCOMMIT1 variable in equation (6.6). We employ correlation analysis with the model. The maximum correlation value in the correlation matrix is 0.950. It is equal to the critical correlation value. Therefore, we employ the linear regression analysis with the model. Unfortunately, we find that a VIF of UEXPER1 is 13.774. This means that multicollinearity still exists in the model.

Secondly, we will put the UREPUTE variable instead of the UEXPER1 variable in equation (6.6). We employ correlation analysis with the model. The maximum correlation value in the correlation matrix is 0.914. It is not a high correlation value. Therefore, we employ the linear regression analysis with the model. Fortunately, we find that no VIF of the model exceeds 10. Based on this evidence, we assume that multicollinearity does not exist in the model. The final modified regression is illustrated in the equation (6.7).

$$UPERS1 = \alpha_1 + \beta_1 UNETWK1 + \beta_2 UAREA1 + \beta_3 UMTRL1 + \beta_4 UREPUTE + \delta_1 \quad (6.7)$$

We will employ the linear regression analysis one more time as Table 24 shows.

Table 24 Revised Coefficients of the US R&D Community: The Individual Regression

Variables	Beta	t	Sig.	VIF
UNETWK1	.084	8.178	.000	3.643
UAREA1	.605	64.508	.000	3.066
UMTRL1	.010	.693	.448	7.203
UREPUTE	-.006	-.425	.671	6.449
Constant		7.909	.000	

Dependent variable: UPERS1
An adjusted R-square: 0.460
N: 18,840 researchers

According to the results in the Table 24, the persistence of Japanese researchers of the semiconductor laser diode R&D community is illustrated in the equation (6.8).

$$\text{UPERS1} = 0.000 + 0.084\ \text{UNETWK1} + 0.605\ \text{UAREA1} + 0.010\ \text{UMTRL} - 0.006\ \text{UREPUTE} \qquad (6.8)$$

Equation (6.8) illustrates that the coefficients of the technological network (UNETWK1) and the research diversity (UAREA1) factors of the US individual model support our hypotheses at the significant level of 0.01. However, the total amount of material related papers (UMTRL1) and the total amount of journal papers (UREPUTE) of the US researcher do not affect his/her persistence significantly.

It is important to emphasize that a UREPUTE variable is a representative variable of the three variables (UTOTAL1, UEXPER1, and UREPUTE). Additionally, their correlation values are in the same direction (positive sign). Therefore, we can interpret the effect of UTOTAL1 and UEXPER1 as a UREPUTE variable does. This means that the sunk cost (UCOMMIT1) and the experimental work (UEXPER1) factors do not affect the US individual persistence significantly.

According to equations (6.5) and (6.8), we notice that the individual persistence regression of both Japanese and US R&D communities are similar. The amount of co-authors (the technological network factor) and the amount of research areas (the research diversity factor) affect the individual persistence significantly. Additionally, the amount of research areas (the research diversity factor) is the most influential factor in both countries.

2. The Organizational Persistence

Consequently, we compare the organizational persistence in the semiconductor laser diode R&D community in Japan and the US. We find that 3,071 organizations join the semiconductor laser diode R&D community. In the Japanese and US R&D communities, there are 1,258 organizations (40.96% of 3,071 organizations) that have contributed their knowledge to the R&D community. There are 336 Japanese organizations (26.70% of 1,258 organizations) and 922 US organizations (73.30% of 1,258 organizations).

Figure 24 shows the trends of the shares of Japanese publications by types of organizations (firm, university, and governmental laboratory). It is observed that the trends of each type of organizations are stable in the last two decades. Japanese universities and firms are major players in the R&D community.

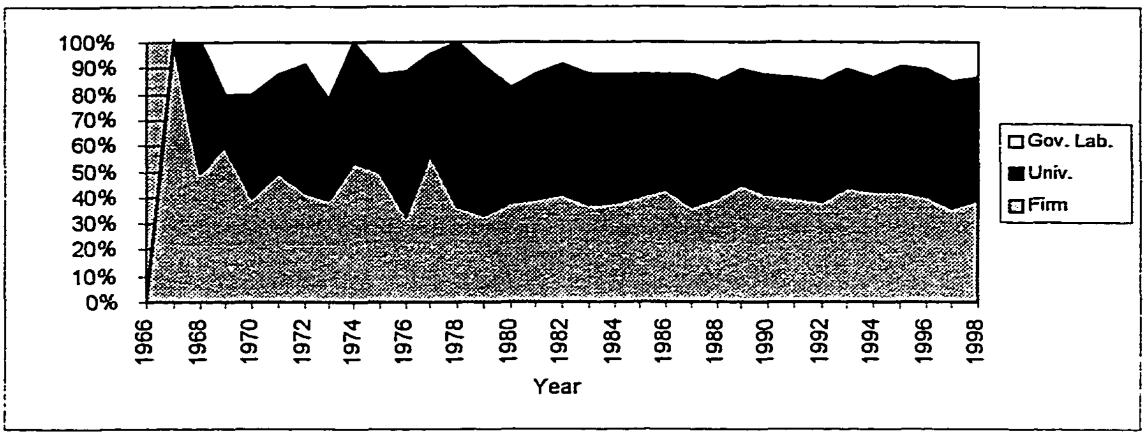


Figure 24 The Japanese Semiconductor Laser Diode R&D Community:

The Organization Level (1966-1998)

Figure 25 shows the trends of the shares of US publications by types of organizations (firms, universities, and governmental laboratories). It is observed that the trend of governmental laboratories seems to be gradually declining. We notice that US universities are increasing their R&D efforts. Japanese universities and firms are major players in the R&D community as well.

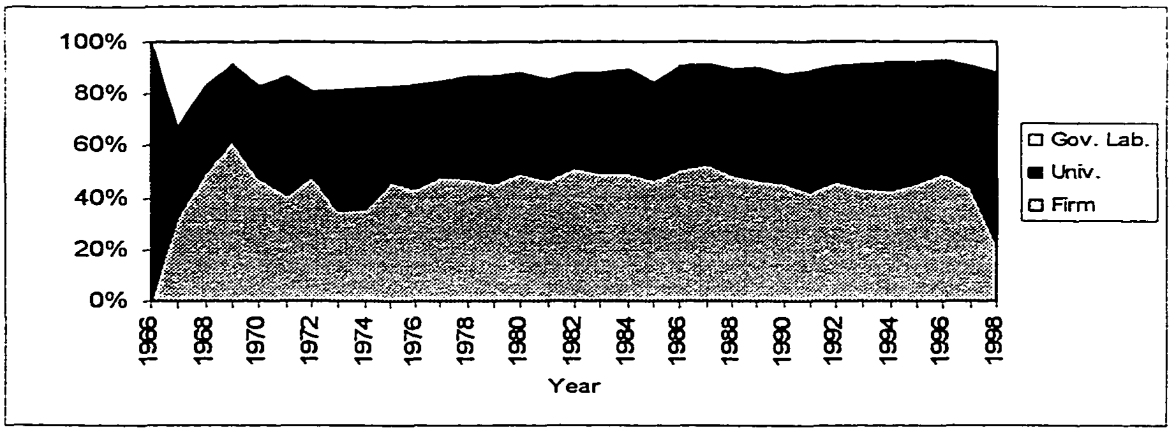


Figure 25 The US Semiconductor Laser Diode R&D Community:

The Organization Level (1966-1998)

We will use the same four interest factors in the organizational persistence used in section 5.3: (1) *organization's commitment*, (2) *geographic location*, (3) *technological capability*, and (4) *organizational types*. Measurement of each factor is also the same as described previously in Table 7.

Regression equations of the Japanese and the US semiconductor laser diode R&D communities are developed based on the organizational hypotheses. The equations are shown in equations (6.9) and (6.10), respectively.

$$JPERS2 = \alpha_2 + \beta_1 JTOTAL2 + \beta_2 JGEOGPH2 + \beta_3 JPATENT2 + \beta_4 (JFIRM2 + JUNIV2 + JGOV2) + \delta_2 \quad (6.9)$$

and

$$USPERS2 = \alpha_2 + \beta_1 UTOTAL2 + \beta_2 UGEOGPH2 + \beta_3 UPATENT2 + \beta_4 (UFIRM2 + UUNIV2 + UGOV2) + \delta_2 \quad (6.10)$$

whereas:

α_2 : a constant value

$\beta_1, \beta_2, \ldots, \beta_4$: coefficient value of each factor

δ_2 : an error value of the regression

JPERS2 and UPERS2: the organization persistence of Japanese and US R&D communities, respectively

JTOTAL2 and UTOTAL2: the organization's commitment factor of Japanese and US R&D communities, respectively

JGEOGPH2 and UGEOGPH2: the geographical factor of Japanese and US R&D communities, respectively

JPATENT2 and UPATENT2: the technological capability factor of Japanese and US R&D communities, respectively

JFIRM2 and UFIRM2: a dummy variable (firm) of Japanese and US R&D communities, respectively

JUNIV2 and UUNIV2: a dummy variable (university) of the Japanese and US R&D communities, respectively

JGOV2 and UGOV2: a dummy variable (governmental laboratory) of Japanese and US R&D communities, respectively

2.1 The F-Test and t-test of the Japanese and US R&D Communities: The Organization Level

We explore both the Japanese and the US R&D communities in the organization level roughly by using descriptive statistics. We find that a Japanese firm persists in the R&D community longer than the US firm on average. Additionally, a Japanese firm tends to have higher performance in PATENT2 than a US firm. Table 25 provides further details.

Table 25: Descriptive Statistics of the Japanese and the US R&D Communities: The Organization Level

Variables	Country	Minimum	Maximum	Mean	Std. Deviation
PERS2	Japan	1	32	7.4345	8.1072
	US	1	33	6.4913	8.1138
TOTAL2	Japan	1	1688	28.3810	121.5742
	US	1	2844	19.1106	108.6969
PATENT2	Japan	0	161	10.80	14.61
	US	0	106	1.03	5.88
FIRM2	Japan	0	1	0.40	0.49
	US	0	1	0.66	0.47
UNIV2	Japan	0	1	0.43	0.50
	US	0	1	0.28	0.45
GOV2	Japan	0	1	0.16	0.37
	US	0	1	0.05	0.23

N(Japan): 336 organizations
N(the US): 922 organizations

In Table 25, although the Japanese R&D community has a higher performance than the US R&D community, their standard deviation values are also higher than the US R&D community. US firms have contributed a larger percentage (66%) than the Japanese firms have (40%) in the R&D community. On the other hand, the Japanese universities and governmental laboratories have contributed a larger ratio than the US universities and governmental laboratories.

We also find that the Japanese organizations have persisted 7.43 years in the R&D community and patented 28.38 patents on average. On the other hand, we find that the US organizations have persisted 6.49 years and patented only 1.03 patents on average. One may question that why the Japanese have patented more than the US organizations while the organizational persistence of both countries differs only in one year. It is possible that the Japanese organizations are larger organizations. We have no evidence at this stage. However, we will consider about the size of organizations (only firms) in the next section.

We employ the F-test and the t-test in order to identify whether variances and means of all variables are the same, respectively. Table 26 provides these details.

Table 26: Independent Sample Test of the Japanese and US in the Semiconductor Laser Diode R&D Communities: The Organization Level

Variables	F-test		t-test	
	F	Sig.	t	Sig.(two –tailed)
PERSIST2	.202	.653	1.825	.068
TOTAL2	4.118	.043	1.296	.195
PATENT2	68.359	.000	15.259	.005
FIRM2	15.927	.000	15.448	.000
UNIV2	61.312	.000	22.379	.000
GOV2	123.434	.000	13.927	.000

N(Japan): 336 organizations
N(the US): 922 organizations

In Table 26, we find that variances of the two variables (PERS2 and TOTAL2) from both Japanese and US organizations are the same at the significant level of 0.01. However, means of PERS2 of both nations are different at the significant level of 0.1, whereas means of TOTAL2 of both nations are not different. On the other hand, the rest of the variables (PATENT2, FIRM2, UNIV2, and GOV) of both nations are different in variances and means at the significant level of 0.01.

2.2 Correlation Analysis of the Japanese R&D Community:

The Organization Level

We will choose to review the Japan organizations first. The correlation analysis will be employed. Table 27 provides the correlation matrix of the Japanese organizations.

Table 27: Correlations of the Japanese R&D Community: The Organizational Level

	JPERS2	JTOTAL2	JPATENT2	JFIRM2	JUNIV2	JGOV2
JPERS2	1.000	.491*** (.000)	.375*** (.000)	-.107** (.050)	.173*** (.001)	-.091* (.097)
JTOTAL2		1.000	.429*** (.000)	.047 (.389)	.008 (.886)	-.074 (.179)
JPATENT2			1.000	.155*** (.004)	-.098* (.072)	-.075 (.171)
JFIRM2				1.000	N/A	N/A
JUNIV2					1.000	N/A
JGOV2						1.000

***: Correlation is significant at the level 0.01 level (2-tailed)
**: Correlation is significant at the level 0.05 level (2-tailed)
*: Correlation is significant at the level 0.1 level (2-tailed)
N/A: not available
N: 336 organizations

The relationships between JPERS2 and JTOTAL2, JPATENT2, and JUNIV2 are positive and significant at the level of 0.01, 0.05, and 0.01, respectively. It is shown that the Japanese organizations that have the greater amount of papers or patents are more likely to persist in the R&D community. Additionally, Japanese universities are more likely to persist in the R&D community.

However, the relationships between JPERS2 and JFIRM2 and JGOV2 are negatively and significant at the level of 0.05 and 0.1, respectively. It is shown that the Japanese firms and governmental laboratories are not likely to persist in the R&D community. It is possible that most Japanese firms focus their fields of interests frequently based on their consumers' need. The Japanese governmental laboratories may change their research based on financial support or the public's interests.

The relationship between JCOMMIT2 and JPATENT2 is positive and significant at the level of 0.01. It is shown that a Japanese organization that has patented is likely to publish more publications. However, the relationships of JCOMMIT2 with JFIRM2, JUNIV2, and JGOV2 are not significant.

The relationship between JPATENT2 and JFIRM2 is positive and significant at the level of 0.01. It is shown that a Japanese firm is likely to patent. However, the relationship between JPATENT2 and JUNIV2 is negative and significant at the level of 0.1. It is shown that a Japanese university is not likely to patent. The relationship between JPATENT2 and JGOV2 is not significant.

Finally, the relationships among JFIRM2, JUNIV2, and JGOV2 are not available (N/A) because they are dummy variables.

We observe that the relationships between JPERS2 and JFIRM2, JUNIV2, and JGOV2 are –0.107, 0.173, and –0.091, respectively. This means that the persistence of Japanese firms is less than the persistence of Japanese universities and governmental laboratories. Therefore, we use a JFIRM2 variable as a reference variable in the Japanese regression model.

Generally, we find that no correlation value is high. Although the relationship value between JFIRM2 with JUNIV2 is -0.723, these variables are dummy variables in the regression. When we employ the linear regression, we use JFIRM2 variable as a based variable. This means that we do not put JFIRM2 in our regression. Therefore, we employ the linear regression technique directly. The results are shown in Table 28.

Table 28: Coefficients of the Japanese R&D community: The Organizational Level

Variables	Beta	t	Sig.
JTOTAL2	.394	7.793	.000
JPATENT2	.229	4.479	.000
JUNIV2	.206	4.126	.000
JGOV2	.034	.693	.489
Constant		7.780	.000

Dependent variable: JPERS2.
An adjusted R-square: 0.304.
N: 336 organizations

According to the results in the Table 28, the organizational persistence regression is shown in equation (6.11) at significant level of 0.01, except the JGOV2.

$$JPERS2 = 0.000000 + 0.394\ JTOTAL2 + 0.229\ JPATENT2 + 0.206\ JUNIV2 + 0.034\ JGOV2 \qquad (6.11)$$

Equation (6.11) illustrates that coefficients of the organization's commitment (JTOTAL2) and the technological capability (JPATENT2) of the Japanese organizations support our hypotheses at the significant level of 0.01. Furthermore, the Japanese universities have higher persistence 0.206 times than the Japanese firms at the significant level of 0.01. However, the Japanese governmental laboratories do not have higher persistence than the Japanese firms significantly.

2.4 Correlation Analysis of the US R&D Community: The Organization Level

We will now analyze the US organization R&D community, following the same procedures that we did in the Japanese organization R&D community. Table 29 provides more details.

Table 29: Correlations of the US R&D Community: The Organizational Level

	USPERS2	UTOTAL2	UPATENT2	UFIRM2	UUNIV2	UGOV2
USPERS2	1.000	.365*** (.000)	.309*** (.000)	-.341*** (.000)	.304*** (.000)	.107*** (.001)
UTOTAL2		1.000	.702*** (.000)	-.077** (.019)	.064* (.051)	.033 (.319)
UPATENT2			1.000	.055* (.098)	-.071** (.032)	.025 (.444)
UFIRM2				1.000	N/A	N/A
UUNIV2					1.000	N/A
UGOV2						1.000

*** : Correlation is significant at the level 0.01 level (2-tailed)
** : Correlation is significant at the level 0.05 level (2-tailed)
*: Correlation is significant at the level 0.1 level (2-tailed)
N/A: not available
N: 922 organizations

In Table 29, the relationships between UPERS2 and UTOTAL2, UPATENT2, UUNIV2 and UGOV2 are positive and significant at the level of 0.01, 0.05, 0.01, and 0.01, respectively. It is shown that US organizations who have the greater amount of papers and/or patents are more likely to persist in the R&D community. Additionally, US universities and governmental laboratories are also more likely to persist in the R&D community.

However, the relationship between UPERS2 and UFIRM2 is negative and significant at the level of 0.1. It is shown that US firms are not likely to persist in the R&D community. It is possible that the US firms change their fields of interests frequently based on their consumers' needs.

The relationships between UCOMMIT2 and UPATENT2, and UUNIV2 are positive and significant at the level of 0.01, and 0.1, respectively. It is shown that the US organizations that have patented are likely to publish more publications. Additionally, US universities are likely to publish more publications. Most university researchers need to publish papers because of their competition and evaluation system.

However, the relationship between UCOMMIT2 and UFIRM2 is negative and significant at the level of 0.1. US firm researchers may change their fields of interest frequently. Some may not have any interest in publishing papers. Their evaluation system may be different from the university researchers. However, the relationship of UCOMMIT2 and UGOV2 is not significant.

The relationship between UPATENT2 and UFIRM2 is positive and significant at the level of 0.01. It is shown that the US firms are likely to patent. Firms need to achieve new technologies. When their researchers discover important issues, they will patent their knowledge.

However, the relationship between UPATENT2 and UUNIV2 is negative and significant at the level of 0.05. It is shown that the US universities are not likely to patent their knowledge. They may study only in "Scientific Boundary" (Albridge, 1999). However, the relationship between UPATENT2 and UGOV2 is not significant.

Finally, the relationships among JFIRM2, JUNIV2, and JGOV2 are not available (N/A) because they are dummy variables.

We observe that the relationship between UPERS2 and UFIRM2, UUNIV2, and UGOV2 are –0.341, 0.304, and –0.107, respectively. This means that the persistence of US firms is less than the persistence of US universities and governmental laboratories. Therefore, we use a UFIRM2 variable as a reference variable in the US regression model.

2.5 Linear Regression Analysis of the US R&D Community: The Organization Level

According to the correlation matrix in the last section, we find that no correlation value is too high. Although a correlation value between UFIRM2 and UUNIV2 is -0.872, but they are dummy variables in the regression. When we employ the linear regression, we use UFIRM2 variable as a reference variable. This means that we do not put UFIRM2 in our regression. Therefore, we employ the linear regression technique directly. The results are shown in Table 30.

Table 30: Coefficients of the US R&D Community: The Organizational Level

Variables	Beta	t	Sig.
UTOTAL2	.214	5.234	.000
UPATENT2	.178	4.364	.000
UUNIV2	.325	11.035	.000
UGOV2	.147	5.051	.000
Constant		13.701	.000

Dependent variable: USPERS2.
An adjusted R-square: 0.244.
N: 922 organizations

In Table 30, all beta coefficients are significant at 0.01. According to the results in the Table 30, the organizational persistence regression of the US semiconductor laser diode R&D community is shown in the equation (6.12) with significant level of 0.01.

$$USPERS2 = 0.000000 + 0.214\ UTOTAL2 + 0.178\ UPATENT2 + 0.325\ UUNIV2 + 0.147 UGOV2 \quad (6.12)$$

The equation (6.12) illustrates that coefficients of the organization's commitment (UTOTAL2) and the technological capability (UPATENT2) of the US organizations support our hypotheses at the significant level of 0.01. Furthermore, the US universities and US governmental laboratories have higher persistence 0.325 and 0.147 times, respectively, than US firms at the significant level of 0.01.

In the organizational level, the persistence of the Japanese and US organizations is affected by the organization's commitment, the technological capability, and types of organization factors significantly. The universities and governmental laboratories of both countries have higher persistence than firms do. According to our hypotheses in the organizational level, the H7, H9, and H10 are supported based on the evidence.

3. The Firm Persistence

We find that firms play a major role in the Japan – US semiconductor laser diode R&D community in the organizational level. There are 744 (59.14% of 1,258 organizations) firms in the R&D community. The rest are universities and governmental laboratories. Since we are only interested in firms that are located in Japan and the US, we cannot employ some variables (e.g., GEOGPH2, UNIV2, and GOV2) in the organizational model properly. Therefore, we have to modify the organizational model.

One may suggest that if a firm has unlimited resources such as employees and good financial support, they may persist in the R&D community longer than others may. It is possible that a large firm may persist in the R&D community longer than a small firm. Therefore, we add two more variables, employee (MEN3), and total sales (SALE3) in a modified organizational model.

We collected data from Corporate Technology Information Services Inc. [488 firms (65.59% of 744 firms in the Japan and the US R&D community)]. There are 92 Japanese firms (67.64% of 136 Japanese firms) and 396 US firms (65.13% of 608 US firms). The modified model is shown in equations (6.13) and (6.14), respectively.

$$JPERS3 = \alpha_3 + \beta_1 JTOTAL3 + \beta_2 JPATENT3 + \beta_3 JMEN3 + \beta_4 JSALE3 + \delta_3 \qquad (6.13)$$

and

$$USPERS3 = \alpha_3 + \beta_1 UTOTAL3 + \beta_2 UPATENT3 + \beta_3 UMEN3 + \beta_4 USALE3 + \delta_3 \quad (6.14)$$

whereas:

α_3 : a constant value

$\beta_1, \beta_2, \ldots, \beta_4$: coefficient value of each factor

δ_3 : an error value of the regression

JPERS3 and USPERS3: the organization's persistence of the Japanese and US R&D communities, respectively

JTOTAL3 and UTOTAL3 : the organization's commitment factor of the Japanese and US R&D communities, respectively

JPATENT3 and UPATENT3 : the technological capability factor of the Japanese and US R&D communities, respectively

JMEN3 and UMEN3: the numbers of employees of a firm in 1998 of the Japanese and US R&D communities, respectively

JSALE3 and USALE3: the total sales of a firm in 1998 (× $1M) of the Japanese and US R&D communities, respectively

3.1 The F-Test and t-Test of the Japanese and the US R&D Communities : The Firm Level

We explore the Japanese and the US R&D communities roughly by using descriptive statistics. We find that a Japanese firm persists in the R&D community longer than the US firm on average. Additionally, a Japanese firm tends to have higher performance than a US firm. Table 31 provides more details.

Table 31: Descriptive Statistics in the Japanese and the US R&D Communities: The Firm Level

Variables	Country	Minimum	Maximum	Mean	Std. Deviation
PERS3	Japan	1	32	8.74	8.93
	US	1	31	5.47	7.24
TOTAL3	Japan	1	1688.00	61.0870	208.9009
	US	1	2844.00	18.1212	148.4099
PATENT3	Japan	0	243	15.28	38.35
	US	0	106	1.73	8.45
MEN3	Japan	150	331852	29021.71	59058.97
	US	1	600000	12436.26	47269.51
SALE3	Japan	643.00	142394.00	61718.522.	138759.74
	US	0.13	178174.00	3536.1681	16272.936

N(Japan): 92 firms
N(the US): 396 firms

In Table 31, we find that Japanese firms have higher performance than the US firms have on average. One may notice that the minimum sales and employees of the US firms are only \$130, 000 (\$0.13 M) and 1 employee, respectively. On the other hand, the minimum sales and employees of the Japanese firms are \$643,000,000 (\$643 M) and 150 employees. This indicates that Japanese firms that join in the semiconductor laser diode R&D community are large firms. However, the Japanese firms have higher standard deviation values than those of the US firms.

We will employ the F-test and the t-test techniques in order to learn whether variances and means of variables of the Japanese firms and the US firms are the same, respectively. Thus, we have set null hypotheses of variances and means of all variables of both nations are the same. Table 32 provides the results.

Table 32: Independent Sample Test of the Japanese and US Firms in the Semiconductor Laser Diode R&D Communities

Variables	F-test		t-test	
	F	Sig.	t	Sig.(two –tailed)
PERSIST3	11.614	.001	3.271	.001
TOTAL3	13.647	.000	1.866	.065
PATENT3	115.208	.000	3.370	.001
MEN3	8.605	.004	2.513	.013
SALE3	128.767	.000	4.015	.000

N(Japan): 92 firms
N(the US): 396 firms

In Table 32, we find that all significant values in the F-test are less than 0.01. This means that we reject our null hypothesis. We assume that the variances of all variables of both nations are not the same at the significant level of 0.01. In the t-test column, we find that means of PERSIS3, PATENT3, and SALE3 of both nations are not the same at the significant level of 0.01. The means of TOTAL3 and MEN3 of both nations are not the same at the significant level of 0.1 and 0.05, respectively.

3.2 Correlation Analysis of the Japanese R&D Community: The Firm Level

We employ the correlation analysis between dependent and independent variables. Table 33 provides more detail.

Table 33 Correlations of the Japanese R&D Community: The Firm Level

	JPERS3	JTOTAL3	JPATENT3	JMEN3	JSALE3
JPERS3	1.000	.640*** (.000)	.691*** (.000)	.750*** (.000)	.345*** (.000)
JTOTAL3		1.000	.379*** (.000)	.732*** (.000)	.457*** (.000)
JPATENT3			1.000	.593*** (.000)	.285*** (.000)
JMEN3				1.000	.612*** (.000)
JSALE3					1.000

***: Correlation is significant at the level 0.01 level (2-tailed)
N: 92 firms

In Table 33, we find that correlation values between dependent and independent variables are not very high. All correlation values are less than the critical value and significant at the 0.01 level (2-tailed) such as correlations between JPERS3 with JTOTAL3, JPATENT3, JMEN3, and JSALE3, respectively.

The relationships between JPERS3 and JTOTAL3, JPATENT3, JMEN3, and JSALE3 are positive and significant at the level of 0.01. This means that our hypotheses are supported. The Japanese firms that have the great amount of papers, patents, employees, or total sales are more likely to persist in the R&D community. We will explore several significant relationships among the independent variables as well.

The relationships between JTOTAL3 and JPATENT3, JMEN3, and JSALE3 are positive and significant at the level of 0.01. It is shown that Japanese firms that have the greater amount of patents, employees, or total sales are more likely to have the greater amount of papers.

The relationships between JPATENT3 and JMEN3, and JSALE3 are positive and significant at the level of 0.01. It is shown that Japanese firms that have the greater amount of employees, or total sales are more likely to have the greater amount of patents.

The relationship between JMEN3 and JSALE3 is positive and significant at the level of 0.01. It is shown that Japanese firms that have the greater amount of total sales are more likely to have the greater amount of employees.

3.3 Linear Regression Analysis of the Japanese R&D Community: The Firm Level

We employ the linear regression technique directly because there is no mullticollinearity in the Japanese firm R&D community model. The results are shown in Table 34.

Table 34: Coefficients of the Japanese R&D Community: The Firm Level

Variables	Beta	t	Sig.	VIF
JTOTAL3	.247	2.238	.028	2.273
JPATENT3	.370	3.849	.000	1.724
JMEN3	.231	1.772	.080	3.153
JSALE3	-.063	-.854	.395	1.004
Constant		7.581	.000	

Dependent variable: JPERS3
An adjusted R-square: 0.533
N: 92 firms

According to the results in Table 34, the organizational persistence regression is shown in equation (6.15).

$$JPERS3 = 0.000 + 0.247\ JTOTAL3 + 0.370\ JPATENT3 + 0.231\ JMEN3 - 0.063\ JSALE3 \quad (6.15)$$

The equation (6.15) illustrates that the firm's commitment (JTOTAL3), the firm's technological capability (JPATENT3), and the firm's employees (JMEN3) factors affect the Japanese firm persistence significantly. However, the total sales (JSALE3) factor does not affect the Japanese firm persistence significantly.

3.4 Correlation Analysis of the US R&D Community: The Firm Level

We employ the correlation analysis with the US firms in the semiconductor laser diode R&D community. The following table (Table 35) shows the correlations among the dependent variable and the independent variables.

Table 35 Correlations of the US R&D Community: The Firm Level

	UPERS3	UTOTAL3	UPATENT3	UMEN3	USALE3
UPERS3	1.000	.319*** (.000)	.445*** (.000)	.374*** (.000)	.336*** (.000)
UTOTAL3		1.000	.744*** (.000)	.205*** (.000)	.214*** (.000)
UPATENT3			1.000	.300*** (.000)	.247*** (.000)
UMEN3				1.000	.886*** (.000)
USALE3					1.000

***: Correlation is significant at the level 0.01 level (2-tailed)
N: 396 firms

We find that correlation values among dependent and independent variables are not high in Table 35. All correlation values are less than 0.95 and significant at the 0.01 level (2-tailed) such as correlation values between UPERS3 with UTOTAL3, UPATENT3, UMEN3, and USALE3, respectively.

The relationship between UPERS3 and UTOTAL3, UPATENT3, UMEN3, and USALE3 are positively and significant at the level of 0.01. This means that our hypotheses are supported. The US firms that have the greater amount of papers, patents, employees, or total sales are more likely to persist in the R&D community. We also explore several significant relationships among the independent variables.

The relationship between UTOTAL3 and UPATENT3, UMEN3, and USALE3 are positively and significant at the level of 0.01. It is shown that US firms that have the greater amount of patents, employees, or total sales are more likely to have the greater amount of papers.

The relationship between UPATENT3 and UMEN3, and USALE3 are positively and significant at the level of 0.01. The US firms that have the greater amount of employees or total sales are more likely to have the greater amount of patents.

The relationship between UMEN3 and USALE3 is positively and significant at the level of 0.01. US firms that have the greater amount of total sales are more likely to have the greater amount of employee.

3.5 Linear Regression Analysis of the US R&D Community: The Firm Level

We will employ the linear regression technique directly with US firms in R&D community by using SPSS. The results are given in Table 36.

Table 36: Coefficients of the US R&D Community: The Firm Level

Variables	Beta	t	Sig.	VIF
UTOTAL3	-.024	-.357	.721	2.297
UPATENT3	.385	5.707	.000	2.411
UMEN3	.209	2.166	.031	4.921
USALE3	.061	.647	.518	4.776
Constant		13.510	.000	

Dependent variable: UPERS3
An adjusted R-Square: 0.255
N: 396 firms

Table 36 shows that the coefficients of the US firms' technological capability (UPATENT3) and number of employees (UMEN3) support our hypotheses significantly. This means that these factors affect the US firm persistence. On the other hand, the firm's commitment (UTOTAL3) and total sales (USALE3) do not affect to the US firm persistence significantly.

According to the results in Table 36, the organizational persistence regression is shown in equation (6.16).

$$UPERS3 = 0.000 - 0.024UTOTAL3 + 0.385UPATENT3 + 0.209UMEN3 + 0.061USALE3 \qquad (6.16)$$

In the firm level, we observe that the Japanese firm persistence is affected by the amount of literature, patents, and employees significantly. On the other hand, the US firm persistence is affected by the amount of patents, and employees significantly.

4. Conclusions

This chapter attempted to test the differences between the Japanese and US semiconductor laser diode R&D communities on many levels. We classify our comparison study into three levels: individual, organization, and firm levels. We employ frameworks we developed in the study of the R&D community. On each level, we tested the differences of variances and means of all variables of both countries. Consequently, we tested the relationship between dependent variable and independent variables of both countries.

First, on the individual level, we find that the variances and the means of all variables of Japanese and the US R&D communities are different significantly. We also find that the technological network and the research diversity factors affect the individual persistence of both countries significantly. Other factors do not support our hypotheses significantly.

Secondly, on the organization level, we find that the variance of PERSIST2 and the mean of TOTAL2 variables of both countries are not different significantly. However, the variances and the means of other variables of both countries differ significantly. We also find that the organization's commitment, the technological capability, the types of organization factors of both countries affect the organizational persistence significantly.

Finally, on the firm level, we find that the variances and the means of all variables on this level from both countries differ significantly. We also find that the firm's commitment, technological capability, number of employees factors affect to the persistence of Japanese firms significantly. On the other hand, the firm's technological capability and number of employee factors affect the persistence of US firms significantly.

CHAPTER VII

CONCLUSIONS

1. Discussion on the Persistence Models

This dissertation is designed to analyze what factors affect the persistence of members of the semiconductor laser diode R&D community. Members of the R&D community are classified into three levels: (1) individual, (2) organizational, and (3) national levels. Therefore, we have proposed three persistence models accordingly: (1) the individual, (2) the organizational, and (3) the national models. Each model consists of a set of factors that may affect the persistence. Consequently, each model is tested.

First, we propose the individual persistence model that consists of the *sunk cost*, the *technological networks*, the *experimental work*, the *research diversity*, the *technological characteristics*, and the *reputation* approaches. The model is supported significantly. This means that *all factors* in the model affect the individual persistence.

It should be noted that some factors have a higher relationship with other factors. They are the *sunk cost*, the *experimental work*, and the *reputation* factors. As discussed earlier, one or more of the higher relationships among the factors (independent variables) causes multicollinearity. Therefore, we employ model respecification method by grouping them together. The new individual persistence model is shown in Figure 26.

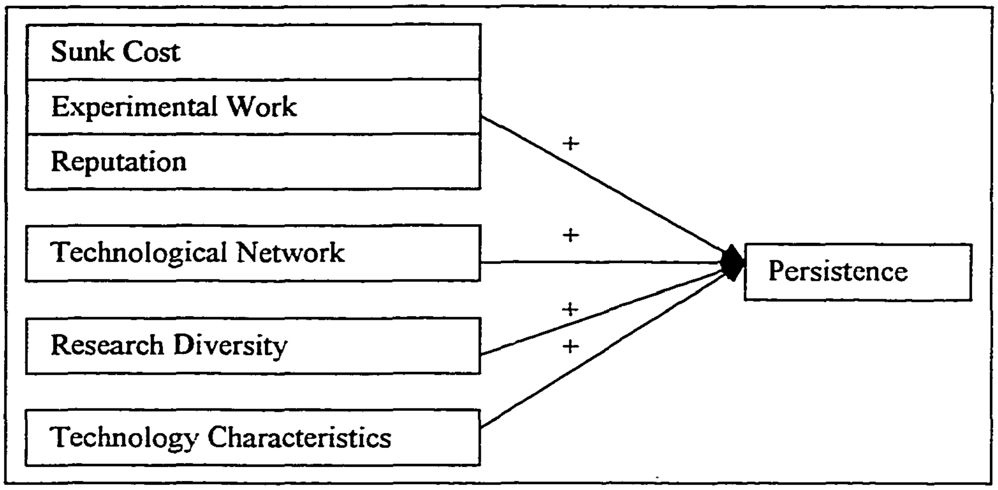


Figure 26: An Individual Persistence Model

Secondly, we have proposed the organizational persistence model. The model consists of the *organization's commitment*, the *geographic location*, the *technological capability*, and the *types of organization* approaches. The organizational persistence model is also supported significantly. This means that *all factors* in the model affect the organizational persistence. The organizational persistence model is shown in Figure 27.

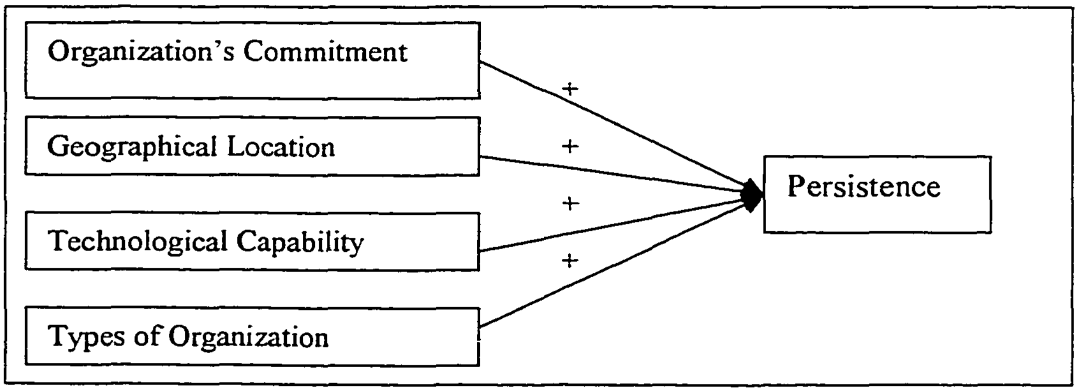


Figure 27: An Organizational Persistence Model

Finally, we have proposed the national persistence model. The national persistence model consists of several factors including, the *technological prerequisites,* the *manpower,* the *knowledge diversity,* the *technological infrastructure*, and the *sociocultural tendency* approaches. Based on the results, mulitcollinearity was found in the model, therefore some factors are grouped together. They are the *technological prerequisites,* the *manpower,* the *knowledge diversity,* and the *technological infrastructure* factors.

We combine the four variables into one variable. A productivity environment variable is created. Therefore, a modified national persistence model consists of two independent variables. Based on the results, the productivity environment factor affects the national persistence positively. On the other hand, the *socioculututral tendency* approach has inverted relationship with the national persistence. The new national persistence is shown in Figure 28.

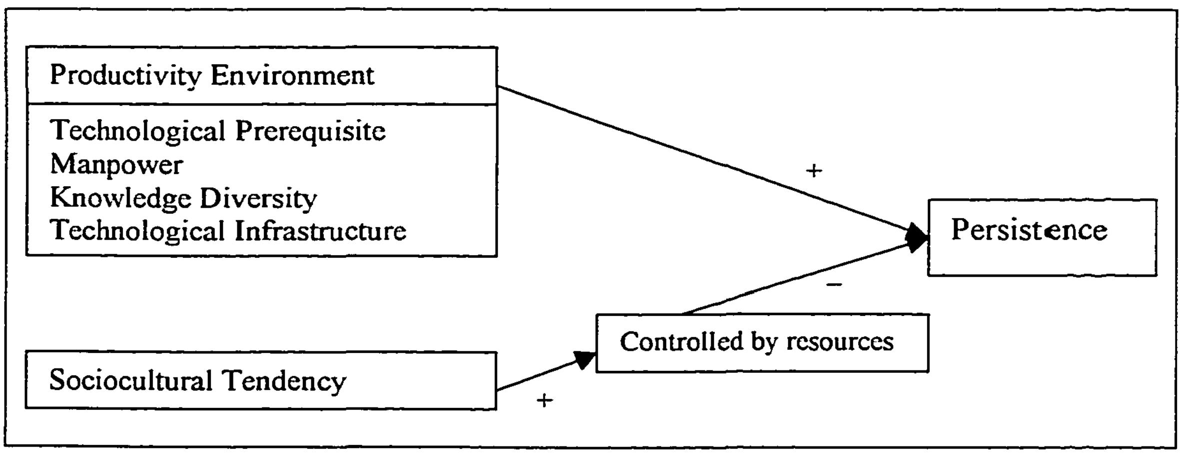


Figure 28: A National Persistence Model

2. The Comparison Study of Japan and the US Semiconductor Laser Diode R&D Communities

We extend our study into specific countries. Since Japan and the US are leaders of the semiconductor laser diode technology, it is interesting to find out whether the R&D communities of both countries are similar. We determine to study (compare) R&D communities of both countries into three specific levels: (1) the individual, (2) the organization, and (3) the firm levels.

We employ the models we previously employed in the individual level of the R&D community with the new individual level. We modify the organizational model to fit with the organizational and the firm model by removing the *geographical location* factor and adding two more control variables, the *total amount of employees* and the *total sales* in the organizational, and the firm levels, respectively.

First, we explore the Japanese and the US R&D communities roughly. We find that a Japanese researcher has a significantly higher performance in all factors (the *sunk cost*, the *technological networks*, the *experimental work*, the *research diversity*, the *technological characteristics*, and the *reputation* approaches.) We also find that the variances and the means of all factors of both countries are different significantly.

Additionally, we find that the *technological networks* and the *research diversity* factors affect to the individual persistence of both Japanese and US R&D communities in the individual level significantly. However, the other factors do not affect the individual persistence significantly.

Secondly, we explore the Japanese and US organizations roughly. We find that the means of the *organization's commitment* factor of both countries in the organization level are statistically not different. The means and variances of the rest factors (the *technological capability* and the *types of organization*) are statistically different. We determine that on average, the Japanese organizations have a higher performance than US organizations. We also find that *all factors* (the *total amount of literature*, the *amount of patents*, and the *types of organizations*) affect the organizational persistence of both countries significantly.

Finally, we focus only on the Japanese and the US firms. We find that the means and the variances of all factors (the *total amount of literature*, the *total amount of patent*, the *total amount of employee*, and the *total sales*) of both countries are different. On average, we state that the Japanese firms have a higher performance than the US firms have.

We also find that the *total amount of literature*, the *amount of patents*, and the *amount of employees* factors affect the persistence of the Japanese firms significantly. On the other hand, we find that only the *total amount of patents*, and the *amount of employees* factors affect the persistence of the US firms significantly.

3. Discussions on Research Methods and Future Research

The "bibliotech" technique has been employed in many studies (Culnan, 1986; Lievrouw, 1989; Woleck and Sanchez, 1993; and Reid, 1997). However, most studies employ a citation analysis technique. We realized that bibliography databases provide rich information entries such as authors, their affiliations, their title, and dates of their publication and other information.

Therefore, we determine to employ the "bibliotech" technique in our study. We decide to study the persistence behavior of members of an R&D community. The INSPEC electronic database is selected. We also study the semiconductor laser diode R&D community. The INSPEC provides bibliographic data of the semiconductor laser diode R&D community.

According to the publication procedures, we understand that the publication process may be delayed. Basically, the publication procedures take a year or more on average. Therefore, we do not consider the data in 1998, only from 1966 to 1997. However, we have obtained a great amount of data because of the advantages of new electronic databases. We receive a significant portion of data and analyze it by this means.

Based on our methodology, we find that the "bibliotech" technique can be employed in our study appropriately. The individual, organizational, and national models have all been tested. The results show that the models are supported significantly.

Our research is designed to understand what factors affect the persistence of researchers, organizations, and nations in the semiconductor laser diode R&D community. It is a useful study for managers and policy makers in order to conduct their R&D efficiently.

It is well known that technologies change rapidly. One may have a desire or interest to know what the market leaders of the semiconductor laser diode are doing. Technology mapping is another interesting topic. This study leads us to understand the direction of research areas that the market leaders conduct. Bibliography data is an appropriate tool for this kind of study.

It should be noted that *reverse causality* may consider in the future study. We have studied influential factors (independent variables) that affect the persistence of members (dependent variables) of the R&D community. Therefore, it is possible that the variables we are treating as "dependent" variables in this study, may in fact be "independent" variables and could be used in predicted variables that we are including as "independent."

4. The Validation of Semiconductor Laser Diode Technology

We chose the semiconductor laser diode technology based on three reasons. First, the semiconductor laser diode is in a semiconductor technology which is considered to be an excellent example of a growing and innovative industry (Malerba, 1985). Secondly, the bibliographical data in an electronic database is available from 1966 to present. Finally, we have found that Japan and the US are major players in the semiconductor laser diode R&D community. Therefore, we would like to see some structures of both countries.

One may criticize that the findings from the semiconductor laser diode R&D community have only limited external validity. There is a defined need to validate the findings through a careful analysis of other technology communities. According to our literature survey, some scholars are interested in the persistence of the *individual level* (Rappa and Garud, 1992; Rappa and Debackere, 1995) and in the *organizational level* (Debacker, Clarysse, and Rappa, 1994).

Rappa and Garud (1992) study the persistence of researchers in the field of *cochlear implant*, which is defined as an *emerging technology*. They found that the legitimacy of the field and the size of the research community affect the persistence of researchers. However, the group size and group productivity factors are not supported in their study. A reason might be that the number of cumulative co-authors does not adequately capture the entire spectrum of collaboration.

Rappa and Debackere (1995) study the persistence of researchers in the field of *neural networks*, which is also defined as an *emerging technology*. They discovered that early entrants in the field have had unique motivations to enter and to persist in their chosen field of research.

Debackere, Clarysse, and Rappa (1994) study the persistence of organizations in the field of *transgene plant*. The transgene plant is defined as an *emerging technology*. They found that, " the embeddedness and position of an organization in a network of ongoing collaborations appeared to be strong and positive determinant of its persistence." However, the productivity factor as measured by the amount of publications, is not supported in their study.

This dissertation is a unique study. It can be described by three special reasons. First, we study the persistence of members of the semiconductor laser diode R&D community which are categorized into three groups (researchers, organizations, and nations). Secondly, we have collected a great amount of data (49,250 records). There are 66 countries joined with this R&D community. Finally, no study has the time comprehensive time of study longer than this study to our knowledge or findings.

Based on our findings, some findings are different from other studies. For example, we find that the researcher's technological network, as measured by the numbers of cumulative co-authors, is supported in the individual level. Furthermore, we find that the amount of publications (organization's commitment) is supported in the organizational level.

We summarize the persistence studies which are studied by other scholars in Table 37.

Table 37 Comparison of Persistence Studies of Different R&D Communities

Technology	Cochlear Implant	Neural Network	Transgene Plants	Semiconductor Laser Diode
Stage of technology	emerging technology	emerging technology	emerging technology	well-developed technology
Focused period of time (yr.)	17	N/A	13	33
Demand	low	low	low	high
Competition	low	low	low	very high
Regulation	high	high	high	low
Objective	N/A	N/A	N/A	clear

We realize that frameworks for the four studies are different but they focus on the same topic. These technologies (cochlear implant, neural network, transgene plant, and semiconductor laser diode) have different characteristics. This research can be extended to other semiconductor technologies, but is limited to a degree in some technologies such as biotechnology which requires a long period of study, and has high concern about regulations, lower competition, and lower demand. Some findings may or may not be the same. This study not only identifies itself as a unique study, but also extends more findings in the persistence topic.

5. Managerial Implications

The present research has practical implications not only for researchers who work in the semiconductor laser diode R&D community, but also for managers and national policy makers who are responsible for technological development programs in this community. The following points should be noted.

We found that the organization's commitment factor is supported significantly. Based on our findings, if an organization contributes one more paper to the R&D community, the persistence of the organization will increase by about four months[1]. It should be noted that this is not a statistic interpretation but is provided for an intuitive understanding. The organization's commitment factor is the most influential factor that affects to the persistence of organization.

We also find that the researcher's sunk cost factor is supported significantly. Based on our findings, if a researcher contributes one more paper, his/her persistence will increase eighteen days[2]. This is also provided for an intuitive understanding. It is also shown that the total amount of papers factor into how researchers contribute to the R&D community, which affects their persistence.

Considering "researchers" as a resource of an organization, if a researcher in an organization contributes more publications, the organization is more likely to persist in the R&D community. Not only the researchers benefit, but also the organization as well. Therefore, managers might encourage their researchers to publish more papers.

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[1] A statistical interpretation is all things being equal, if the total amount of papers that an organization contributes to the R&D community increases one paper, the persistence of the organization will increase four months at the significant level of 0.01.

[2] A statistical interpretation is all things being equal, if a researcher increases one research area, his/her persistence will increase eighteen days at the significant level of 0.01.

However, it should be noted that managers should consider a balance of "exploration" and "exploitation" of new knowledge. Exploring new knowledge is an important issue, but also exploiting new knowledge for revenue purposes should be addressed as well. It is good to be an "inventive" organization, however it is better to be an "innovative" organization.

We found that the researcher's technological network factor is supported significantly. Based on our finds, if a researcher increase his/her co-authors by one person, he/she will increase his/her persistence for one and a half months[3]. Additionally, we also found that the researcher's research area factor is supported significantly. Based on our findings, if a researcher increases one research area, his/her persistence will increase about six months[4]. This factor is the most influential factor in the individual level. Again, both of the above findings can be used for further intuitive understanding.

Management should create an environment where their researchers are enthusiastic to share their knowledge to each other. Furthermore, management should establish informal groups of researchers that cross organizational boundaries and come together to discuss their knowledge and practices that the group needs to learn about. This would encourage researchers to continue their work and/or influence them to explore new techniques and directions. The organization would therefore benefit from the researchers sharing their techniques and knowledge.

We found that the geographical location factor is supported significantly. Based on our findings, if an organization is located in a high density of knowledge, the

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[3] A statistical interpretation is all things being equal, if a researcher increase his/her co-author one person, his/her persistence will increase one and a half months at the significant level of 0.01.
[4] A statistical interpretation is all things being equal, if a researcher increases one research area, his/her persistence will increase six months at the significant level of 0.01.

organization's persistence will increase about one month[5]. The result, though not statistical in nature, can be used for intuitive understanding. Our findings are also supported by Mansfield and Lee's study (1996).

Although new knowledge is considered as a public good, Mansfield and Lee (1996) found that firms located in the nation and areas where academic research occurs are significantly more likely to have an opportunity to be among the first to apply the findings of this research rather than distantly remote firms.

Managers should consider their firms' location as a factor that affects their persistence in the R&D community. An example would be that most of the semiconductor laser diode research tends to be more concentrated in certain geographical region, e.g., the US and Japan, and usually in more high-tech cities, e.g., Silicon Valley (USA) and Tokyo (Japan).

We found that the organization's technological capability factor is supported significantly. Managers should consider to enhance their researchers to patent their knowledge. Based on our findings, if an organization increases one patent, the persistence of an organization will increase eighteen days[6]. Again, though this is not a statistical interpretation, it is made available here for intuitive understanding. It should also be noted that managers should consider the timeframe of "when" to patent because the patent process may disclose documents. Sometimes, competitors will take advantage from the new patents.

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[5] A statistical interpretation is all things being equal, if an organization is located in a high density knowledge, its persistence will increase one month at the significant level of 0.01.

[6] A statistical interpretation is all things being equal, if the total amount of papers that an organization contributes to the R&D community increases one paper, the persistence of the organization will increase four months at the significant level of 0.01.

Managers should provide resources such as patent databases, financial support, and rewards in order to enhance research productivity. By providing these supportive resources to their researchers, managers will also contribute to the longevity of the organization.

We found that academic researchers are more likely to persist in the R&D community longer than other researchers. Based on our findings, academic researchers have persisted in the semiconductor laser diode R&D community about 1.25 times of firms' researchers. This means that academic researchers are potentially a good and reliable source of knowledge acquisition.

Mansfield and Lee (1996) state that universities play a major role in originating and promoting the diffusion of knowledge and techniques. It is known that academic researchers are well-trained researchers. They have both in theoretical knowledge and tacit knowledge. Therefore, academic researchers are a good and reliable source of knowledge acquisition.

6. National Policy Implications

According to our study framework, we find several interesting results. These findings may lead to several implications.

We find that the nation's productivity environment factor is supported significantly. The productivity environment factor is a composite factor which includes the total amount of literature, numbers of researchers, research areas, and organizations of a nation. Based on our findings, if a productivity environment increases by one unit, the nation's persistence will increase by about five months[7]. It should be noted that this is provided for intuitive understanding.

According to characteristics of the productivity environment factor, national policy makers should consider all four factors. Furthermore, they should consider other influential factors in individual and organizational levels because they may affect at the national level. For example, the total amount of literature of a nation is calculated by summarizing all papers (papers, conference proceedings, and patents) contributed by researchers or organizations in the nation. Therefore, the following suggestions are proposed:

1. Policy makers should provide good facilities such as libraries (hardware), and databases (software) that allow researchers to use them. It is a well-known fact that researchers consistently use the output of R&D community (papers, patents, and conference proceedings) to study more of their research interests. Patents are a good example. In the late 20th century, technology leading countries forced other countries to establish more patent regulations. It is well-known that patents are considered as "trade weapons." Most developing countries are learning about the value of having patents, especially within the last two decades. Of course, they promote and encourage their people to patent their knowledge, but it can be a very expensive and time-consuming process sometimes, in some countries. Additionally, some countries have not provided patent databases to the public yet. Therefore, it is sometimes

[7] A statistical interpretation is all things being equal, if the productivity environment of a nation increases one unit, the persistence of the nation will increase five months at the significant level of 0.01.

difficult to obtain good, reliable, and up-todate feedback because of the lack of these resources.

2 Policy makers should create an environment where researchers are enthusiastic to share their knowledge with each other such as national or regional seminars every year. Promotion of research should further generate and encourage additional papers and conference proceedings. This, as noted previously, increases the persistence of researchers in the R&D community.

As discussed earlier under the managerial implications, researcher's technological network and research area factors are supported significantly. Policy makers should promote an interdisciplinary policy. The interdisciplinary policy may be employed in a project evaluation process. This would encourage researchers to look for other researchers who work in related fields and would be more conducive for them to explore and work with new people and ideas.

We also found that the researcher's reputation factor is supported significantly. Based on our findings, if a researcher publishes one paper in a journal, his/her persistence will increase by about ten days[8]. This is also provided for intuitive understanding. We would like to propose two implications in this topic:

1. Policy makers should offer awards to researchers who contribute the best papers or patents each year. Generally, most countries do this.
2. Policy makers should provide more channels of reputation. In a highly competitive environment, many papers are rejected by higher quality journals. The researchers should have more choices, such as more journals, or

[8] A statistical interpretation is other thing being equal, if a researcher increases one journal paper, his/her persistence will increase ten days at the significant level of 0.01.

conference proceedings, to contribute their knowledge. As discussed earlier, the implications of being published, as well as presenting and/or attending conferences, will offer opportunities for researchers to share their knowledge as well as learn from others. This promotes diversity in one aspect which may lead to further investigations/research and also promotes recognition and acceptance of existing and possibly new research. By researchers obtaining visibility through publications and presentations, the greater persistence he/she will have in the R&D community and in their organizations.

APPENDIX A

INTERVIEWS

Researcher #1 August 31, 1999

Major Physics, Research University, USA

Researcher's Persistence

1. Why do you have an interest in the semiconductor laser diode technology?

I can say that it is because of my career, a physicist. Actually I am interested in atomic. When I was a Ph.D. student, I was interested in Hydrogen atoms. However, I conduct research that is related to semiconductor for more than ten years now.

2. How do you form your group to conduct a research?

I have six to ten graduate students and two post-doctorate students. We discuss what we are interested and conduct research accordingly. I also work with ten professors. I work with them based on common interests, central facilities, and multidisciplinary interests. It is a loose organization but effective.

3. **What factor(s) do you think may affect your persistence?**

My opinion is two things:

1. *Good facilities,* and
2. *Curiosity in my work.*

4. In my models, which factors may affect to researcher's persistence?

5 4 3 2 1	most ⟶ least
NETWORK	5
EXPERIMENTAL	5
AREAS	4
MATERIALS	3
COMMITMENT	3
REPUTATION	(BLANK)

5. **Will this technology continue? Why?**

Yes, it will. This technology is important in communication. However, semiconductor technology is an electronic technology. It may have reached its limitation. Based on the S-curve theory, a new interesting technology is quantum optics, which is a light-photon base technology.

Researcher # 2 September 2, 1999

Major Engineering, Research University, USA

Researcher's Persistence

1. **Why do you have an interest to conduct research in the semiconductor laser diode technology?**

Actually, I do not have an interest in this technology. I am interested in the radiation affect and reliability of microelectronics, ME. My research is steered to improved quality of microelectronic devices in space. This field is becoming a more important field. We would like to increase the lifetime of microelectronic devices in space.

I am interested in this field because of my former career, when I worked at Sandia National Laboratory. I started to conduct research in this field in 1984 until now.

2. **How do you form your group to conduct a research?**

At the Sandia National Laboratory, there are three types/levels of projects. Researchers should conduct research in all levels.

1. *Principle Investigator (Individual Investigator)*

This type of project is considered as an individual project.

2. *Assemble a team in laboratories*

This type of project requires many experts to conduct a research in laboratories. Sometimes, a researcher can form his/her group with permission.

3. Formally/Informally

Researchers have to work or discuss with other researchers around the world in a week.

3. What factor(s) do you think it may affect to your persistence in the R&D community?

There are many factors that may affect to my persistence. They are as follows:

1. The technology is still interesting.

2. Unsolved problem

Many devices are invented and needed to be tested. Technology is changed rapidly. No one knows exactly which one is the best device.

3. Still get paid

I can say that it is my career and fortunately I still am being sponsored to conduct research.

4. In my models, which factors may affect a researcher's persistence?

(blank)

5. Will the technology continue? Why?

Yes, it will. The market is growing. Many communication satellites are launched. We need long life communication satellites. Of course, we also need long life microelectronic devices in space.

Researcher #3 September 3, 1999

Major Physics, Research University, USA

Researcher's Persistence

1. **Why do you have an interest to conduct research in the semiconductor laser diode technology?**

   I do not conduct research in this technology directly. My field of interest is related to the interaction of laser light in materials. When I was a Ph.D. student, I was interested in the nuclear structure of physics. Because nuclear technology is very complicated, I had to work with large groups of researchers. Additionally, the technology requires sophisticated equipment. I thought it was perhaps not a good career choice. I do not want to work within a large group either. Therefore, I changed my interest field.

2. **How do you form your group to conduct a research?**

   I discuss with my research assistants and my students. Sometimes, I also work with other professors when I need to use specific equipment that I do not have. For example, I work with some professors in Italy in nanocrystal metal technology.

3. **What factor(s) do you think it may affect to your persistence in the R&D community?**

   There are three as follows:

   1. *Funding:*

   It is the most important factor.

2. Scientific Boundary:

I am only interested in R&D in science boundary. I do not want to go into the engineering boundary. Once I understand the problem that I study in the science boundary, I will stop my research and find other interesting topics.

3. Curiosity driving force:

I think it is a basic scientist's sense. If other scientists do not find it interesting, then I probably won't either.

4. In my models, which factors may affect a researcher's persistence?

(blank)

5. Will this technology continue? Why?

Yes, it will. This technology becomes important to the public. Unfortunately, I think I will conduct research in this field only three to five years. Since I can understand my problem, I will stop further research.

Researcher #4 September 6, 1999

Major Physics, Research University, USA

Researcher's Persistence

1. **Why do you interest in the semiconductor laser diode technology?**

   There are three as follows:

   1. Personal interesting,
   2. Funding, and
   3. Important to society

2. **How do you form your group to conduct a research?**

I have on-going groups. They have been formed for a long time. They are made up of my students and my colleagues. When I work with my students, I have to work with them two to five years until they graduate. When I work with my colleagues, I work based on common interests. I can say that it is a loose organization.

3. **What factor(s) do you think it may affect to your persistence in the R&D community?**

There are several factors such as:

1. Availability of funds,
2. Availability of facilities (such as equipment and manpower), and
3. Student's working projects

4. In my models, which factors may affect to researcher's persistence?

5 4 3 2 1 most ——► least

NETWORK	4
EXPERIMENTAL	3
AREAS	2
MATERIALS	3
COMMITMENT	4
REPUTATION	4

5. Will this technology continue? Why?

Yes, it will. Since semiconductor is based on silicon (Si), there are about four to five materials that have interesting microstructures, e.g., diamonds. It is interesting to study their combinations and performance.

BIBLIOGRAPHY

Abernathy, W.J., and Clark, K.B. "Innovation: Mapping the Winds of Creative Destruction." Research Policy, Vol.14, pp.3-22, 1985.

Abernathy, William J., and Utterback, James M. "Patterns of Industrial Innovation." Technology Review, Vol.80, pp.40-47, 1978.

Afuah, Alan. Innovation Management. Oxford University Press, 1998.

Allen, Thomas J. "Distinguishing Engineers from Scientists." In Managing Professionals in Innovative Organizations, Ed. by Ralph Katz, Ballinger Publishing Co., Cambridge, USA, pp.3-18, 1988.

Almeida, Paul. "Knowledge Sourcing by Foreign Multinationals: Patent Citation Analysis in the U.S. Semiconductor Industry." Strategic Management Journal, Vol.17, pp.155-165, 1996.

Anderson, Philip. "Toward Exemplary Research in the Management of Technology - An Introductory Essay." Journal of Engineering and Technology Management, Vol.10, pp.7-22, 1993.

Archibugi, Daniele, Evangelista, Rinaldo, and Simonetti, Roberto. "Concentration, Firm Size and Innovation: Evidence from Innovation Costs." Technovation, Vol.15, No.3, pp.153-163, 1995.

Auger, C.P. Information Sources in Patents. Bowker-Saur, New York, 1992.

Ayres, R. "Barriers and Breakthroughs: An Expanding Frontiers' Model of Technology-Industry Life Cycle." Technovation, Vol.7, pp.87-115, 1988.

Bacharach, Samuel B. "Organization Theories: Some Criteria for Evaluation." Academy of Management Review, Vol.14, No.4, pp.496-515, 1989.

Badawy, Michael K. "One More Time: How to Motivate Your Engineers." In Managing Professionals in Innovative Organizations, Ed. by Ralph Katz, Ballinger Publishing Co., Cambridge, U.S.A., pp.19-26, 1988.

Badawy, Michael K. "Technology and Strategic Advantage: Managing Technology Transfer in the U.S. and Japan." International Journal of Technology Management, pp.205-215, 1991.

Bates, Kimberly A. "Innovation History and Competitive Advantage: A Resource-based View Analysis of Manufacturing Technology Innovations." Best Paper, Proceedings of the American Academy of Management, Vol.55, pp.235-239, 1995.

Bhattacharjya, Ashoke S. "Composition of R&D and Technological Cycles." Journal of Economic Dynamics and Control, Vol.20, pp.445-470, 1996.

Bowen, Michael G. "The Escalation Phenomenon Reconsidered: Decision Dilemmas or Decision Errors?" Academy of Management, Vol. 12, No.1, pp.52-66, 1987.

Brockner, Joel, Rubin, Jeffrey Z. and Lang, E. "Face Saving and Entrapment." Journal of Experimental Social Psychology, Vol.17, 1981, pp.68-79.

Bye, Pascal, and Chanaron, Jean-Jacques. "Technology Trajectories and Strategies." Int. Journal of Technology Management, Vol.10, No.1, pp.45-65, 1995.

Clark, K.B. "Competition, Technical Diversity, and Radical Innovation in the U.S. Auto Industry." In Research on Technological Innovation, Management and Policy, Ed. by R.S. Roosenbloon, pp.103-49, Jai Press, Greenwich, 1983.

Comroe, J.H. Jr. and Drippd, R.D. "Scientific Basis for the Support of Biomedical Science," Science, Vol. 192, pp.105-111, 1976.

Constant, E. W. "The Social Locus of Technological Practice." In The Social Construction of Technological Systems, Ed. by W.E. Bijker, et al., Cambridge: MIT Press, 1987.

Courtial, Jean-Pierre, and Sigogneau, Anne. "How to Use Scientific and Technological Information to Reveal Strategic Technologies." Int. J. Technology Management, Vol.10, No.1, pp.45-65, 1995.

Crane, Donald P. "A Dynamics System for Management Development." Personnel Journal, pp.667-674, 1972.

Culnan, Mary J. "The Intellectual Development of Management Information Systems, 1972-1982: A Co-Citation Analysis." Management Science, Providence, Vol.32, No.2, pp.156-172, 1986.

Daft, R., and Becker, S. Innovation in Organization. Elsevier, New York, 1978.

Daft, Richard L., Lengel, Robert H. "Organizational Information Requirement, Media Richness and Structural Design." Management Science, pp.554-571, May 1986.

Debackere, Koenraad, Clarysse, Bart, and Rappa, Michael A. "Survival in the Network: On the Persistence of Research Organizations in an Emerging Field." Working paper at Alfred P. Sloan School of Management, MIT, 1992.

Debakere, Koenraad, Clarysse, Bart and Rappa, Michael A. "The Application of Sociometric and Even-history Modeling to Bibliometric Data: The Case of Transgene Plants." Working paper at Alfred P. Sloan School of Management, MIT, Feb. 1994.

Debackere, Koenraad, Rappa, Michael A., and Clarysse, Bart, "Autonomy and Persistence in Industrial Research: The Dilemma Revisited." Best Paper, Proceedings of the American Academy of Management, Vol.55, pp.417-421, 1995.

Debackere, Koenraad, Clarysse, Bart, and Rappa, Michael A. "Dismantling the Ivory Tower: The Influence of Networks on Innovative Performance in Emerging Technologies." Technological Forecasting and Social Change, pp.139-154, 1996.

DeLamarter, Richard, Big Blue: IBM's Use and Abuse of Power. New York: Dodd, Mead, 1986.

Dore, Jean-Christophe, Ojasoo, Tiiu, Okubo, Yoshiko, Durand, Thomas, Dudognon, Gerard, and Miquel, Jean-Francois. "Correspondence Factor Analysis of the Publication Patterns of 48 Countries over the Period 1981-1992." Journal of the American Society for Information Science, Vol.47, No.8, pp.588-602, 1996.

Dosi, G. "Technological Paradigms and Technological Trajectories." Research Policy, Vol. 11, pp. 147-162, 1982.

Drucker, Peter F. "New Templates for Today's Organizations." Harvard Business Review, pp.45-53, 1974.

Dunphy, Steven M., Herbig, Paul R., and Howes, Mary E. "The Innovation Funnel," Technological Forecasting and Social Change, Vol.53, pp.279-292, 1996.

Englesman, E.C., and van Raan, A.F.J. "A Patent-based Cartography of Technology." Research Policy, Vol.23, pp.1-26, 1994.

Ernst, H. "Patenting Strategies in the German Mechanical Engineering Industry and Their Relationship to Company Performance." Technovation, Vol.15, No.4, pp.225-240, 1995.

Farrell, J., and Saloner, G. "Standardization, Compatibility, and Innovation." Rand Journal of Economics, Vol.16, pp.71-83, 1985.

Farrell, J., and Saloner, G. "Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation." American Economic Review, Vol.76, No.5, pp.940-955, 1986.

Foster, Richard N. "Working the S-Curve: Assessing Technological Threats." Research Technology Management, Vol. 29, No.4, pp.17-20, 1986.

Foster, Richard N. "Timing Technological Transitions." In Readings in the Management of Innovation, Ed. by Michael L. Tushman and William L. Moore, pp.215-228, 1988.
Frost & Sullivan, Inc. World Industrial and Scientific Laser Systems Markets. California, 1994.

Gibilisco, Stan. Understanding Lasers. Tab Books, USA, 1989.

Garud, R., and Rappa, M. A. "On the Persistence of Researchers in Technological Development." In Academy of Management Best Papers Proceedings, pp. 369-373, 1992.

Gunz, Hugh P., and Gunz, Sarah P. "Professional/Organizational Commitment and Job Satisfaction for Employed Lawyers." Human Relations, pp.801-808, 1994.

Hannan, Michael T. and Carroll, Glenn R. Dynamics of Organizational Populations. Oxford University Press, 1992.

Harry, John E. Industrial Lasers and Their Applications. McGraw Hill, 1974.

Hansen, Povl A. "Publicly Produced Knowledge for Business: When is it Effective?" Technovation, Vol.15, No.6, pp.387-397, 1995.

Hyes, Robert H. and Wheeelright, Steven C. "Matching Process Technology with Product/Market Requirements.", In Reading in the Management of Innovation, Ed. By Michael L. Tushman and William L. Moore, Ballinger Publishing Co., p.422, 1988.

Hecht, Jeff and Teresi, Dick. Laser Supertool of the 1980s. Ticknor & Fields, New York, 1982.

Hendry, John. "Culture, Community and Networks: The Hidden Cost of Outsourcing." European Management Journal, Vol.13, No.2, pp.193-200, June 1995.

Hilpert, U., Regional Innovation and Decentralization: High-Tech Industry and Government Policy. Routledge, London, 1991.

Hinze, Sybille and Grupp, H. "Mapping of R&D Structures in Transdisciplinary Areas: New Biotechnology in Food Sciences." Scientometrics, Vol.37, No.2, pp.313-335, 1996.

Hofstede, G. Culture's Consequences: International Differences in Work-Related Values. Newbury Park, CA, Sage, 1980.

Holt, D.H., Ralston, D.A., and Terpstra, R.H. "Constrainsts on Capitalism in Russia: The Managerial Psyche, Social Infrastructure, and Ideology." California Management Review, Vol.36, No.4, pp.124-141, 1994.

Hout, Thomas M. "Time-Based Competition is Not Enough." Research Technology Management, pp.15-17, July-August 1996.

Hughes, T.P. "The Evolution of Large Technological Systems." In The Social Construction of Technological Systems, Ed. by W.E. Bijker, et al, Cambridge: MIT Press, 1987.

Hurley, John. Organization and Scientific Discovery. John Wiley & Sons, 1997.

Jagtenberg, T. The Social Construction of Science. Reidel, Boston, 1983.

Jenilek, Mariann and Schoonhoven, Claudia Bird, "Managing Innovation in High Technology Firms: Challenges to Organization Theory." In Organizational Issues in High Technology Management. Ed. By Luis R. Gomez-Mejia and Michael W. Lawless, Jai Press Inc., pp.3-18, 1990.

Judge, William Q., Fryxel, Gerald E., and Dooley, Robert S. "The New Task of R&D Management: Creating Goal-Directed Communities for Innovation." California Management Review, Vol.39, No.3, pp.73-85, 1997.

Katz, Ralph, Robenstisch, Eric S. and Allen, Thomas J. "A Study of Technology Transfer in Multinational Cooperative Joint Venture." IEEE Transactions on Engineering Management, Vol.43, No.1, Feb. 1996.

Katz, Raph, Robenstisch, Eric S. and Allen, Thomas J. "Investigating the Not Invent Here (NIH) Syndrome: A Look at the Performance, Tenure, and Communication Patterns of 50 R&D Projects Groups." R&D Management, Vol.12, No.1, 1982.

Katz, M.L. and Shapiro, C. "Thechnological Adoption in the Presence of Network Externalities." Journal of Political Economy, Vol.94, pp.822-841, 1986.

Kimberly, J. "Managerial Innovation." In Handbook of Organizational Design, Vol.1, pp. 84–104. Ed. by P. Nymstrom and W. Starbuck, Oxford University Press, 1981.

Kleinbeck, Uwe and Schmidt, Klaus-Helmut "The translation of Work Motivation into Performance." In Work Motivation, Ed. By Uwe Klienbeck, et al., Lawrence Erlbaum Associates Publishers, 1990.

Krickx, Gguido A., "Vertical Integration in the Computer Mainframe Industry: A Transaction cost Interpretation," Journal of Economics Behavior and Organization, Vol.26, pp.75-91, 1995.

Krugman, Paul. "History and Industry Location: The Case of the Manufacturing Belt." The American Economic Review, pp.80-83, May 1991.

Lamn, Helmut and Myers, David G. "Group-Induced Polarization of Attitudes and Behaviour." In Advances in Experimental Social Psychology, Ed. By L. Berkowitz, New York, Academic Press, 1978.

Latour, B. and Woolgar, S. Laboratory Life. Sage Publication, Beverly Hills, 1979.

Leavitt, H. J. "Applied Organizational Change in Industry: Structural, Technological, and Humanistic Approaches." In Handbook of Organizations, pp. 1144–1170. Ed. by J. March, Rand McNally, Chicago, 1965.

Lievrouw, Leach A. "The Invisible College Reconsidered: Bibliometrics and the Development of Scientific Communication Theory." Communication Research, Beverly Hills, Vol.16, No.5, pp.615-627, 1989.

Lee, Mushin and Om, Kiyong. "A Conceptual Framework of Technological Innovation Management." Technovation, Vol.14, No.1, pp.7-16, 1994.

Leonard, Nancy H., Beauvais, Laura L. and Scholl, Richard W. "A Self Concept-Based Model of Work Motivation." Best Paper Proceeding of the American Academy of Management, Vol.55, pp.322-326, 1995.

Leptein, Christopher. "Incentives for Employed Inventors: An Empirical Analysis with Special Emphasis on the German Law for Employee's Invention." R&D Management, Vol.25, No.2, pp.213-225, 1995.

Liu, Shang-Jyh, and Shyu, Joenson. "Strategic Planning for Technology Development with Patent Analysis." Intl. Journal of Technology Management, Vol.13, No.5, pp.661-680, 1997.

Liyanage, Shantha, and Mitchell, Helen. "Strategic Management of Interactions at the Academic-Industry Interface." Technovation, Vol.14, No.10, pp.641-655, 1994.

Luxon, James T. and Parker, David E. Industrial Lasers and Their Applications. Prentice-Hall, 1985.

Lynn, Leonard H., Reddy, N. Mohan, Aram, John D. "Linking Technology and Institutions: The Innovation Community Framework.." Research Policy, Vol. 25, pp.91-106, 1996.

Lynn, Leonard H., Aram, John D., and Reddy, N. Mohan. "Technology Communities and Innovation Communities." Journal of Engineering and Technology Management Jet-M, Vol. 14, pp.129-145, 1997.

Maccoby, Michael, "The American Character: The Organization Man.", Current, Vol. 326, pp.4-9, 1990.

Maitland, I. "Organizational Structure and Innovation: The Japanese Case." In Management by Japanese Systems. Ed. by S. Lee and G. Schwendiman; Prager, New York, 1982.

Malerba, Franco. The Semiconductor Business-The Economics of Rapid Growth and Decline. The University of Wisconsin Press, Wisconsin, 1985.

Malerba, Franco, Orsenigo, Luigi, and Peretto, Pietro. "Persistence of Innovative Activities, Sectoral Patterns of Innovation and International Logical Specialization." International Journal of Industrial Organization. Vol.15, pp.801-826, 1997.

Manners, George E. Jr., Steger, Joseph A., and Zimmerer, Thomas W. "Motivating Your R&D Staff." In Managing Professionals in Innovative Organizations. Ed. by Ralph Katz, Ballinger Publishing Co., Cambridge, U.S.A., pp.19-26, 1988.

Mansfield, Edwin. "Academic Research and Industrial Innovation." Research Policy, Vol.20, pp.1-20, 1991.

Martino, Joseph P. Technological Forecasting for Decision-Making. 3rd ed., McGraw-Hill, Inc., New York, 1993.

Martino, Joseph P. Research and Development Project Selection. John Wiley &Sons, Inc., New York, 1995.

Mathews, John. "Organizational Foundations of Economic Learning." Human Systems Management, Vol.15, pp.113-124, 1996.

McCutchen Jr., William and Swamidass, Paul M. "Effect of R&D Expenditures and Funding Strategies on the Market Value of Biotech Firms." Journal of Engineering Technology Management, Vol.12, pp.287-299, 1996.

Merrifield, D. Bruce. "Measurement of Productivity: Key to Survival." Intl. Journal of Technology Management, Vol.9, No. 5-6-7, pp.771-783, 1994.

Metcalfe, J.S. and Saviotti, Pier Paolo "A Theoretical Approach to the Construction of Technological Output Indicators." Research Policy, pp.141-151, 1984.

Miler, Donal Britton, Managing Professionals in Research and Development. Jossey-Bass Publishers, San Francisco, 1986.

Miller, Roger. "The New Agenda for R&D: Strategy and Integration." International Journal of Technology Management, pp.511-524, 1995.

Miquel, J.F., and Okubo, Y. "Structure of International Collaboration in Science-Part II: Comparisons of Profiles in Countries Using A Link Indicator." Scientometrics, Vol. 29, No.2, pp. 271-297, 1994.

Miquel, J.F., Ojasoo, T., Okubo, Y., Pual, A., and Dore, J.C. "World Science in 18 Disciplinary Areas: Comparative Evaluation of the Publication Patterns of 48 Countries Over the Period 1981-1992." Scientometrics, Vol. 33, No.2, pp. 149-167, 1995.

Moenaert, Rudy, Barbe, Jan, and Deschoolmeester, Dirk. "Turnaround Strategies for Strategic Business Units with an Aging Technology." In The Strategic Management of

Technological Innovation, Ed. by Ray Loveridge and Martyn Pitt, John Wiley & Sons, UK, 1990.

Mogee, Mary Ellen. "Using Patent Data for Technology Analysis and Planning." Research Technology Management, pp.43-49, July-August 1991.

Montgomery, Douglas C. and Peck, Elizabeth A., Introduction to Linear Regression Analysis. Wiley, New York, 1982.

Morita, June G., Lee, Thomas W., and Mowday, Richard T. "The Regression-Analog to Survival Analysis: A Selected Application to Turnover Research." Academy of Management Journal, Vol.36, No.6, pp.1430-1464, 1993.

Mullins, N.C., "The Development of a Scientific Specialty: The Phase Group and the Origins of Molecular Biology." Minerva, Vol.10, pp.51-82, 1972.

Narusis, Marija and SPSS Inc., SPSS for Windows Advanced Statistics Release 6.0. SPSS Inc., Chicago, 1993.

Neff, Michael C. and Shanklin, William L. "Creative Destruction as a Marketing Strategy." Research Technology Management, Vol.40, No.3, pp. 33-40, May-June 1997.

Nelson, R. (Ed.). National Innovation Systems. Oxford University Press, 1993.

Norton, John A., and Bass, Frank M. "Evolution of Technological Generations: The Law of Capture." Sloan Management Review, pp.66-77, Winter 1992.

Okimoto, Daniel I., Sugano, Takuo, and Weinstein, Franklin B. Competitive Edge -- The Semiconductor Industry in the U.S. and Japan. Stanford University Press, CA, 1984.

Padmore, Tim, Schuetze, Hans, and Gibsons, Hervey. "Modeling Systems of Innovation: An Enterprise-centered View." Research Policy, Vol.26, pp.605-624, 1998.

Prahalad, C.K., and Hamel, Gary. "The Core Competence of the Corporation." Harvard Business Review, pp.79-91, May/June 1990.

Parayre, Roch. "The Strategic Implications of Sunk Costs: A Behavioral Perspective." Journal of Economic Behavior and Organization, Vol.28, pp.417-442, 1995.

Patel, Pari and Pavitt Keith. "Is Western Losing the Technological Race?" Research Policy, Vol.16, pp. 55-85, 1987.

Patel, Pari and Pavitt Keith. "The technological competencies of the world's largest firms: complex and path-dependent, but not much variety." Research Policy, Vol.26, pp. 141-156, 1997.

Pegels, C. Carl, and Thirumurthy, M.V. "The Impact of Technology Strategy on Firm Performance." IEEE Transactions on Engineering Management, Vol.43, No.3, pp.246-249, 1996.

Polley, Douglas Eugene. "Persistence and Decision Making Structures: An Experimental Analysis." A dissertation of the Graduate School of the University of Minnesota, 1991.

Porter, A. L., Roper, A. T., Mason, T. W., Rossini, F. A., Banks, J. and Wiederholt, B.J. Forecasting and Management of Technology. John Wiley & Sons, New York, 1992.

Porter, M. Competitive Strategy: Techniques for Analyzing Industries and Competitors. The Free Press, New York, 1980.

Porter, M. The Competitive Advantage of Nations. Macmillan, Inc., New York, 1990.

Ralston, David A., Holt, David H., Terpstra, and Kai-Cheng Yu. "The Impact of Culture and Ideology on Managerial Work Values: A Study of the United States, Russia, Japan, and Korea." Best Paper Proceeding of the American Academy of Management, Vol.55, pp.187-191, 1995.

Rappa, Michael A., Debackere, Koenraad, and Garud, Raghu. "Technological Progress and the Duration of Contribution Spans." Technological Forecasting and Social Change, Vol.42, pp.133-145, 1992.

Rappa, M. A., and Debekere, K. "Technical Communities and the Diffusion of Knowledge." R&D Management, Vol.22, pp.209-220, 1992.

Rappa, M. A., and Debekere, K. "An Analysis of Entry and Persistence Among Scientists in an Emerging Field of Science: The Case of Neural Networks." R&D Management, Vol.25, No.3, pp. 209-220, 1995.

Rappa, Michael and Garud, Raghu. "Using the Literature in the Study of Emerging Fields of Science and Technology." Working paper of Sloan School of Management, MIT,1992.

Ralston, D.A., Gustafson, D.J., Cheung, F., and Terpstra, R.H. "Differences in Managerial Values: A Study of U.S., Hong Kong and PRC Managers." Journal of International Business Studies, Vol.24, N0.2, pp.249-275, 1993.

Rebentisch, Eric S., and Ferretti, Macro. "A Knowledge Asset-based View of Technology Transfer in International Joint Ventures." Journal of Engineering and Technology Management, Vol.12, pp.1-25, 1995.

Reid, Edna O.F. "Evolution of A Body of Knowledge: An Analysis of Terrorism Research." Information Processing & Management, Oxford, Vol.33, No.1, pp.91-106, 1997.

Ricks, D.A., Toyne, B. and Martinez, Z. "Recent Development in International Management Research." Journal of Management, Vol.16, No.2, pp.219-253, 1990.

Rogers, E. Diffusion of Innovations. 3rd Ed., The Free Press, New York, 1982.

Rush, Howard, Hobday, Mike, Bessant, John and Arnold, Erik. "Strategies for Best Practice in Research and Technology Institutes: An Overview of a Benchmarking Exercise." R&D Management, Vol.25, No.1, 1995, pp.17-31.

Sakakura, Shogo, and Kobayashi, Masakazu. "R&D Management in Japanese Research Institutes." Research Policy, Vol.20, pp.531-558, 1991.

Sanchez, Angel Martinez. "R&D and Firm Size: Some Evidence from Spain." Technovation, Vol.14, No.2, pp.63-68, 1994.

Saviotti, Pier Paolo. "Information, Variety and Entropy in Technoeconomic Development." Research Policy, pp.89-103, 1988.

Saviotti, Pier Paolo. "Technology Mapping and the Evaluation of Technical Change." International Journal of Technology Management, pp.407-425, 1995.

Schoenecker, Timothy S. "Factors Affecting A Firms' Commitment to Innovation." Best Paper: Proceedings of the American Academy of Management, Vol.55, pp.52-55, 1995.

Simon, H.A. Administrative Behavior. Free Press, New York, 1973.

Spigel-Rosing, I.S., "Journal Authors as an Indicator of Scientific Manpower: A Methodological Study Using Data for the Two Germanies and Europe." Science Studies, Vol.2, pp.337-359, 1972.

Stainer, Gary. "The Creative Organization." In Managing Professionals in Innovative Organizations, Ed. by Ralph Katz, Ballinger Publishing Co., Cambridge, MA, pp.201-214, 1988.

Stehr, N. and Ericson, R.V. The Culture and Power of Knowledge. Berlin: Walter de Gruyter and Company, 1992.

Staw, Barry M., "Knee-Deep in the Big Muddy – A Study of Escalating Commitment to a Chosen Course of Action." Organizational Behavior and Human Decision Processes, New York, pp. 27-42, June 1976.

Staw, Barry M. and Ross, Jerry. "Behavior in Escalation Situations: Antecedents, Prototypes and Solutions." In Research in Organizational Behavior, Ed. By Larry L. Cumming and Barry M. Staw, Vol.9, JAI Press , Greenwich, 1987.

Stuart, Toby E. and Podolny Joel M. "Local Search and the Evolution of Technological Capabilities." Strategic Management Journal, Vol.17, pp.21-38, 1986.

Stewart, John A. Drifting Continents and Colliding Paradigms. Bloomington: Indiana University Press, 1990.

Sviridov, F.A. The Role of Patent Information in the Transfer of Technology. Pergamon Press, New York, 1981.

Szulanski, Gabriel. "Unpacking Stickiness: An Empirical Investigation of the Barriers to Transfer Best Practice Inside the Firm." Best Paper: Proceedings of the American Academy of Management, Vol.55, pp.437-441, 1995.

Teece, David, J. "Competition, Cooperation, and Innovation: Organizational Arrangements for Regimes of Rapid Technological Progress." Journal of Economic Behavior and Organization, pp.1-25, June 1992.

Teece, David J. "Firm Organization, Industrial Structure, and Technological Innovation." Journal of Economic Behavior & Organization, Vol.31, pp.193-224, 1996.

Thierry, Henk "Intrinsic Motivation Reconsidered." In Work Motivation, Ed. By Uwe Klienbeck, et al., Lawrence Erlbaum Associates Publishers, 1990.

Tingstad, James E. How to Manage the R&D Staff. Amacom Books, New York, 1991.

Utterback, James M. Mastering the Dynamics of Innovation. Harvard Business School Press, Massachusetts, 1994.

Van De Ven, Andrew H. "Central Problems in the Management of Innovation." Management Science, Vol.42, No.5, pp.590-607, May 1986.

Van de Ven, Andrew H. "A Community Perspective on the Emergence Innovations." Journal of Engineering and Technology Management, Vol.10, pp.23-51, 1993.

Walker, Richard D. Patents as Scientific and Technical Literature. The Scarecrow Press, Inc., New Jersey, 1995.

Wade, James. "A Community-Level Analysis of Sources and Rates of Technological Variation in the Microprocessor Market." Academy of Management Journal, Vol.39, No.5, pp. 1218-1244, 1996.

Wilson, J. "Innovation in Organizations: Notes Toward a Theory," In Approaches to Organizational Design, Ed. By J. Thompson, Univ. of Pittsburgh Press, Pittsburgh, 1966.

Whittington, R. "Changing Control Strategies in Industrial R&D." R&D Management, pp.43-53, 1991.

Wood, Samuel C. The Development of Laser Diodes at Sony: A Case Study. Stanford Graduate School of Business, Stanford University, 1995.

Woleck, Francis W. and Sanchez, Peter M. "Research Administrators as "invisible college" facilitators." SRA Journal, Chicago, Vol.24, No.4, pp.27-32, 1993.

Yamada, H. "The Emergence of A New Technology: The Case of Semiconductor Laser Diodes." Master Thesis, Massachusetts Institute of Technology, 1990.

Zaltman, G., Duncan, R., and Holbek, Innovation and Organizations. Wiley, New York, 1973.

Ziman, J. Knowing Everything About Nothing. Cambridge University Press, Cambridge, 1987.

Interviews

Prof. Tolk, interview by author, written, Dept. of Physics and Astronomy, Vanderbilt University, August 31, 1999.

Prof. Fleetwood, interview by author, written, Dept. of Electrical and Computer Engineering; Vanderbilt University, September 2, 1999.

Prof. Haglund, Jr., interview by author, written, Dept. of Physics and Astronomy, Vanderbilt University, September 3, 1999.

Prof. Albridge, interview by author, written, Dept. of Physics and Astronomy, Vanderbilt University, September 6, 1999.

Mary Dietrich, Ph.D., interviewed by author, written, Academic Computing and Information Services, Vanderbilt University, September 10, 1999.