Knowledge Economics in the Information Age

BY

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Abstract of the Dissertation

"Knowledge Economics in the Information Age"

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Though many economists and social scientists agree that knowledge is important and that the study of its influences upon the society and economy should be emphasized, only limited research has been done on impact of knowledge on the economy. The results derived from various studies tell us that the trend of shifting from a traditional industrial-based economy to a knowledge-based economy is inevitable. Hence, my main research questions are: what the relevance of knowledge capital is and what its economic implications are to our society, and can a significant relationship between economic growth and knowledge capital investment can be found?

In the theoretical part of my dissertation I establish an overlapping generation model to capture the accumulation and transfer of knowledge capital. The model is intuitive; nonetheless, it suggests several important socio-economic phenomena. Furthermore, I believe that this model can be applied towards understanding the technological research and development investment behavior of business organizations. The results of my model should provide better insight for academia and businesses for further research in the field of knowledge economics.

In the empirical study part of my dissertation I find that there is a general decline in the awards of science and engineering degree at the university level over the recent decades in the United States. Meanwhile the enrollment rate in S&E displays a ten year cyclical pattern. This pattern may predict future trends in U.S. higher education and the corresponding changes in the economic structure. In addition, I find that R&D spending has a positive correlation with GDP growth. The statistical data further indicates that when the economy grows, more people would pursue graduate level degrees, and more Master's and Ph.D. level graduates and R&D investment in the economy help GDP growth. What this could suggests is that there is a higher demand for well-trained and highly-educated 'knowledge workers' in a highly developed economy. Consequently, increase supply of 'knowledge workers' in the total labor force would push the economy away from a traditional industrial and labor-based economy to a knowledge-based economy.

Dedication

In memory of my great grand mother.
And to my families, professors and friends.

Table of Contents

Table of Figures

Introduction

> "Knowledge is the only meaningful resource today. The traditional factors of production have not disappeared. But they have become secondary. They can be obtained, and obtained easily, provided there is knowledge. And knowledge in this new meaning is knowledge as a utility, knowledge as the means to obtain social and economic results." -- (Drucker, 1993).
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> "In an economy where the only certainty is uncertainty, the one sure source of lasting competitive advantage is knowledge." – (Nonaka, 1991).
>
> "With everything else dropping out of the competitive equation, knowledge has become the only source of long run sustainable competitive advantage." – (Thurow, 1996).

Over the past few decades, some fundamental economic and structural changes in many developed countries have been observed -- the shifting of capital-based industries to knowledge-based industries. The change took place simultaneously with the new invention of and the on-going progress in telecommunications, computing, micro-electronics and bio-engineering. Indeed, it is almost certainly undeniable that the driving force of the economy of the 21st century will be emphasized heavily on technology innovation, human-capital and knowledge.

Knowledge is the most precious resource that the human race has. Unlike natural resources that deplete over time, knowledge accumulates over time, and it becomes more important and valuable through the creation and sharing of new knowledge. In fact, many great thinkers of the last century have come up with the same conclusion: Knowledge is the only meaningful resource today that sustains the national economy on a competitive edge.

Now more and more corporations have increased their competitiveness and productivity by using different analytical approaches of thinking and different technologies to decrease the resources and costs used in order to achieve better results. Some big changes in the past decade are the emerging new style of management in the industries -- "information management" and "knowledge management". Many corporations, like McKinsey, Microsoft and IBM feature positions like "director of knowledge management" and/or "CIO - chief information officer". Information management and knowledge management now can be planned, budgeted and controlled as corporate input and not merely as technology investment (Strassmann, 1998).

The role of information and knowledge in the business has been emphasized. It serves not only the purpose of managing but also value-adding to a corporation's apparent value. Yet, the value of intellectual property is in its use, not in its cost. That is why people value information and knowledge capital when there is a use for it and when there is someone willing to pay for it.

> "The dependence on traditional capital efficiency-based measures of performance is why information finds practically no place among the typical performance metrics examined by corporate executives, auditors, and investors. Yet accumulations of information and knowledge are implicitly recognized every day when companies are bought at a large multiple of their financial value." – (Strassmann, 1998)

As matter of fact, a firm's knowledge capital is often referred to as its intellectual capital or intellectual assets, and can be identified in its workforce (human capital), its customers' demands and preferences, and its system, products, processes, and capabilities. The value of the knowledge assets of a firm may thus significantly exceed the value of its tangible assets (Burton-Jones, 1999). In fact, Drucker (1993) also pointed that three industrial revolutions could be observed in past three hundred years. The first was the industrial revolution, the second was the productivity revolution and the third was the management revolution. And underlying all three phases is fundamental change in the meaning of knowledge. He said, "We have moved from knowledge to knowledge(s)."

Though many economists and social scientists (Burton-Jones, 1999; Drucker, 1993; Nelson and Phelps, 1966; Nonaka, 1991; Schumpeter 1934) agree that knowledge is important and that the study of its influences upon the society and economy should be emphasized only limited research has been done on impact of knowledge on the economy. The results derived from various studies tell us that the trend of shifting from a traditional industrial-based economy to a knowledge-based economy is inevitable. Hence, my main research questions are – what the relevance of knowledge capital is and what its economic implications are to our society, and can a significant relationship between economic growth and knowledge capital investment can be found?

In this dissertation, I confine my research in the following topics:

1. Identifying the scope of knowledge capital and its relevance to the economy.
2. Establishing economic models for knowledge accumulation and transfer analysis.
3. Inspecting the relationship between economic performance, higher education and research and development (R&D) investment and expenditure.

In chapter 1, I review the contemporary knowledge economic literatures. An introduction to Nonaka's theory of knowledge creation is provided and an extension to his theory is presented. I also summarize empirical findings on organizational-level and macro-level research from these knowledge economic literatures. In chapter 2, I establish the microeconomic theoretical ground for analyzing knowledge capital at individual level or at organizational level. I develop mathematical models for knowledge capital accumulation and transfer based on economic principles. I test my model using empirical data in chapter 3. Due to the difficulties in gathering micro-level data, I decide to use macro-level data for my analysis because it is readily accessible and some macro-level factors can be treated as proxies to the variables in my model. Finally, I conclude my findings and propose future research in chapter 4.

Chapter 1

In the literatures of knowledge economics, Joseph Schumpeter (Schumpeter, 1934, 1939) was the first to be given credit for recognizing the importance of knowledge and technological innovation in economic growth. He believed that innovation lay at the center of economic change. He proposed that the taxonomy of technological change is based on three stages: invention, innovation, and diffusion. The foundational principles of economic theory involve the study of capital and labor as the central aspects of production. Capital means tangible physical assets such as land, machines, houses and production materials. The labor input mentioned in production usually means the input of 'man power'. However, what economists rarely mention is the factor of "thinking" and "knowledge": that is "brain-power". According to post-industrial theory the production of goods will decline in favor of services, and knowledge will become the basis of economic growth and productivity (Burton, 1999). Until now, it is commonly noted that our society is marching into the knowledge-centered, technology-driven industrial era. However, the process of creating, transferring and valuating the knowledge is still poorly understood. Thus, we often undervalue knowledge as a means of production factor due to the difficulties of measuring the contribution of knowledge in production.

In the past twenty years many economists have contributed their efforts to understanding the economics of knowledge, technology and innovation. Major contributions in knowledge economic literature were made by Nelson and Phelps (1966), Nelson (1981), Pavitt (1989), Heilbroner and Thurow (1994), Rosenberg (1996), Nelson and Romer (1996), Markusen and Carr (2001), and others. They have laid out the foundation for studies in knowledge economics by pointing out the following:

- Creation of new knowledge or technology can only happen in the human brain.
- Knowledge is through accumulation via informal mechanisms such as "learning-by-doing" or "learning-by-interacting"
- Knowledge is mostly generated internally and usually is specific to some certain application. Thus its value for broader application can not be appreciated immediately.
- The diffusion of knowledge and technology become faster fueled by the diffusion itself and external new technology inputs.
- Economic growth is significantly related to technological advance.
- Consolidation on the issue of intellectual property right should be asserted by the global community.

To understand better the nature of knowledge and its role in the production factor, Nonaka (1991, 1994), Nonaka and Takeuchi (1995), Burton-Jones (1999), Guilhon (2001) have identified knowledge as "explicit" and "tacit". Explicit knowledge is referred as the knowledge that can be codified or expressed by external means, and thus make it understandable to other audiences, and also make the transfer of knowledge easier.

Tacit knowledge is usually referred as experiences and special talents embedded in a person. It is difficult to make tacit knowledge explicit because tacit knowledge is not as transparent as explicit knowledge. For example, a master chief could not tell his apprentices why he can cook well, but after years of practice and observation by working with the master chief some apprentices might develop the skill. On the other hand some might never develop the skill. Thus, the skills of the master chief are passed onto some his apprentices without explicit expression. Nonaka (1994) further pointed out the knowledge conversion in four possible modes: tacit to explicit, explicit to explicit, explicit to tacit and tacit to tacit. The creation of knowledge in an organization lies in the interaction and iteration of these modes. He further proposed a "Spiral" model of knowledge creation. I shall revisit Nonaka's theory and model later in this chapter.

Changing Markets

Why is knowledge important in our economy? Much we know about economics was established on the markets we know – product, labor and capital. In recent decades the markets have been altered more rapidly by the introduction of new technologies, new merchandise and new services. These factors added 'knowledge' and 'technology' influences to the economy. Although economists did say technology was one of the factors that affected productivity gain, only recently economists began to take the knowledge factor in our economy more seriously because:

1. new knowledge creates new products and services
2. knowledge enhances labor quality
3. knowledge boosts labor mobility and wages
4. new knowledge keeps firms in a competitive position
5. new knowledge and technology (as technology is a product of knowledge) may mean better welfare to the human being
6. new knowledge and technology change the consumer's behavior.

Peter Drucker attested to how knowledge has affected and will affect the business world in a recent speech (Drucker, 2003), "What the technologies affect the business is that there will be a major change in next 10 years. The change is re-definition of businesses and how the customers look you as a business." He pointed out Internet as an example that has changed the global market to a local market. E-commerce, a by-product of the Internet, has changed and will change the economic structure fundamentally. He wrote (Drucker, 2003): "Traditional multinationals will, in time, be killed by e-commerce. The e-commerce's delivery of goods, of services, of repairs, of spare parts, and maintenance will require a different organization from that of any multinational today." He pointed out that we are undergoing an 'Information Revolution' in our society, and this 'Information Revolution', should more correctly be called the 'Knowledge Revolution''. The impact of the information boom not only affects our economy but also the way we live -- the society and the culture as a whole.

For example, a by-product of the Internet, the email, has fundamentally changed business practices. About 25 or 30 ago, people contacted each other by traditional mails, telephone calls and telegrams. A little more than 15 years ago, faxes replaced telegrams and traditional mails to become standard communication method of international business practice. And about 10 years ago, along with the emergence of the Internet, people started to use email as a daily form of communication. Presently, people probably don't check their mailbox everyday, but they probably do check their email everyday if not hourly. Virtually every organization in modern society including government, businesses, schools, the military, and hospitals has been altered as a result of these technological changes. This tells us that our society changes due to the introduction of new technologies. However, the real story behinds the technological advances are cognitive science and knowledge. I shall briefly summarize what changed in the markets we defined in economics:

1. Consumer market: Economists used to define consumer market based on consumable goods, products or merchandises only. Now services, which can be treated as consumable goods, became more important than before. Therefore, it has been included in the consumer market as consumable goods. Services can be pure services to enhance customer's satisfaction or they can create added-value to products. For example, customers could buy furniture on-line at Ikea's website and have the furniture delivered to buyer's home. Additionally, people can also buy services from a professional home decorator to arrange their furniture. So the services provided to the customer are basically information, experience and knowledge of the service provider. And quite often, services can be more costly than the products they support. On-line shopping, introduced less than 10 years ago, is not only gradually changing the consumer's behavior but also the way of distributing goods. The 'service' of delivery and transportation became more than they were needed previously (Drucker 2003). People more often don't go to the store to buy things -- there are stores on the TV or computer in their home; and they are not only buying, they are selling as well from their home. So the economic definition of consumer/buyer and supplier/seller becomes ambiguous. Due to the impact of the Internet, consumers now can do business on the cyberspace and become suppliers as well.

2. Labor market: A new term emerged in the labor market is 'knowledge worker'. 'Knowledge Workers' is the general term for people who used to be called engineers, doctors, professors, technologists, specialists and gurus. What makes knowledge workers different from traditional laborers is the knowledge embedded in these workers. The more valuable the knowledge embedded in the worker, the more expensive the worker will be. What the firm relies on is not the physical labor of knowledge workers, but rather their knowledge (Nonaka, 1995; Burton-Jone, 1999). Knowledge workers existed before, but why has there been a change in the market? The reason is that knowledge workers were not quite 'in the market' before. There were not a lot of them to form a market so they could price themselves. Now there is a market for knowledge workers – highly educated and experienced professionals position themselves in a job market that is different than the traditional labor market. Knowledge workers have their own unique 'prices' that relate to the indigenous knowledge they can contribute. One additional point worth addressing is that the mobility of knowledge workers is much higher than traditional labors. Knowledge workers are much free to come and go between firms and industries, and may even shuttle from country to country, a luxury that traditional laborers may not have because most of traditional laborers are trained to perform very process specific tasks and also because there is a greater supply of laborer than knowledge workers. In other word, it is easier to train a traditional laborer to perform simple tasks than to train a knowledge worker to do complex knowledge works (Argote, Darr and Epple, 1995; Grant and Baden-Fuller 1995).

3. Capital and financial services market: According to Drucker (2003), the capital and financial services institutions are sluggish in adapting the changing economy and society, but certainly they are trying their best to survive the competition both domestically and internationally – there are more competitors due to the globalization of trade and business. As we see today, most financial institutions have became 'transnational', that can mean more profitability; however, it means more risk as well. Financial institutions have to do more than before to satisfy their customers in order to keep them. Drucker (2003) commented that "The dominant financial services institutions have not made a single major innovation in thirty years." I cannot agree with his comment on this point. Let me point out a few changes over the past two decades. First, ATM machines have allowed people to get cash and deposit checks 24 hours a day, seven days a week. People traveling can get cash in other countries directly from their bank account in their home country. Second, credit cards and e-money means that people do not have to carry cash to buy products and services, and they can consume and pay later. In my opinion, the credit card, which can be called as a financial product or service, changes people's consuming behavior greatly. A prior condition to the above two examples is the necessary establishment of central exchange and financial management centers that links all the ATMs worldwide in order to provide these services. Let me point out another three examples that just happened recently in the financial market because of the Internet: on-line banking, on-line shopping and on-line trading of stocks and securities.

Theories of the Firm

When we examine the role knowledge plays in our economic system, we should not neglect to review the theory of firms. Firms are sizeable organizations that can efficiently derive the benefits from knowledge, and firms are one of most reliable sources that knowledge workers can get paid for the knowledge they contribute, and firms are the most viable source for valuating and marketing knowledge. There are four principle theories of firms: transaction cost theory, agency theory, resource based theory and knowledge based theory, which is a derivation of resource based theory.

Transaction cost theory was based on Ronald Coase's famous article "The Nature of the Firm" in 1937. In short, Coase suggested firms exist to respond to market failure. Establishing a firm is done to avoid the cost of using the price mechanism that coordinates the economic system. Thus firms are a collection of entities to economize on the cost of various transactions they would otherwise have incurred through individual market contracting.

Agency Theory suggests that firms exist because there is a need for such organizations to govern, combine and coordinate the inputs of different self-interested individuals in pursuit of common goals. A firm is established also because there is a need for a contractual structure that defines the property rights which the firm benefits from the joint efforts of its participating entities (Alchain and Densetz, 1972).

RBT, Resource Based Theory is built upon Penrose's (1959) work *The Theory of the Growth of the Firm* and the on going work by Teece. Penrose conceptualized the firm as "a collection of productive resources", and the resources are represented by tangible assets such as patented inventions and intangible assets such as reputation, brand image, human capital and knowledge capital. The RBT suggests that firms expand by utilizing the collection of these pre-existing resources. And these bundles of resources would determine the firm's competencies. Proper managing strategies for utilizing these bundles of resources would determine the firm's growth and competitiveness. Grant and Baden-Fuller (1991) proposed "Knowledge-Based Theory" which is drawn upon the RBT and includes some key assumptions:

- Knowledge is the key productive resource of the firm.
- Knowledge is acquired by and, in the case of tacit knowledge, stored by individuals.
- Due to time and cognitive limitations of human beings, individuals need to specialize in the knowledge they acquire.
- Production (value creation through translation of input into outputs) typically requires numerous different types of specialized knowledge.

Each of the above theories offers unique perspectives regarding the role knowledge factor plays in these theories. Nevertheless, each has its strengths and limitations. The agent, firms and market are dynamic in terms of the interaction between different entities and their environmental setting. Most of the models attempt to study the nature of firms in static settings. Thus, while the environment changes or the economic system evolves the assumptions often become the obstacle in the power of prediction in each model.

The Intellectual Property Rights

As society progresses to a knowledge-based economy, a clear connotation regarding the definition of the ownership of property should be clearly specified. Intellectual property rights are a fundamental necessity in establishing the system of the knowledge economy. The value and ownership of knowledge could not be clearly specified if there are no intellectual property rights and no legal protection over them. Alchain (1972), identified three distinct elements of property rights: the right to bear the market value, the right to determine use and the right to exchange the rights to the first two elements. Hall (1989), indicated there are three types of intangible assets that are immediately identifiable in a firm: research and development; goodwill; and intellectual property such as patents, trademarks and copyright. However, works involves higher degree of tacit knowledge is often difficult to define clearly what ought to be protected. Usually, the works that are explicitly expressed have received better legal protection. For example, a music record is very transparent and has a clear definition of the protection over the lyric and tunes by the law. On the other hand, tacit knowledge embedded in people would be hard to protect by intellectual property rights. Hall further categorized intangible assets into two groups, one has property rights and the other does not. Trade marks, patents, copy rights, registered designs and other intangible assets that can have clear representations could be better protected under property rights. Others like market intelligence, customer/supplier relations, reputation, brand image, corporate culture, morale, employee know-how and corporate know-how are the group important to a firm's assets but difficult to define and to enter into the protection of intellectual property rights.

Burton-Jones (1999), summarized some common intellectual property protection mechanisms as follows:

Internal Protection (firm- based)

Tacitness of knowledge

Complexity of knowledge

Firm specificity of knowledge

Knowledge embedding – routines, directives, processes, products

Organizational job design

Incentives for knowledge workers

External Protection (market-based)

Patents

Copyrights

Trade Secrets

Legal contracts with suppliers/collaborators

Industry concentration

Time to market

Time and cost to imitate/replicate

Most of the internal protection mechanisms of knowledge rely on the nature of the knowledge. As a rule of thumb, the harder for the knowledge to be 'externalized' or 'codified' the better the protection it has. However, there is a trade off for the protections rely on the 'tacitness' of knowledge – it could create barriers of knowledge transfer inside the organization. Organizational job design could segregate key firm knowledge into several pieces – that is, at the working environment nobody knows the whole picture. So the people who know how to integrate all the work become important knowledge assets to the firm; the key knowledge workers are also known as 'stake holders' to the firm, are central to the firm's operation. The question is how the firm provides them with incentives to work for the firm. The common practice is to create incentives by turning the 'stake holders' into 'share holders'. However, the stake holder's stock value shifts with market fluctuation. Their incentive to work for the firm could follow market fluctuations as well. That is, binding the knowledge worker with monetary compensation may not always work. In the long-run, creating incentives by offering worker stock options is not only costly, but it could create some managerial problems. Another important strategy in creating incentives for knowledge workers is to give them recognition for their work. The firm should think of how to bind the knowledge workers to the firm by giving them 'social recognition' for their knowledge and their contribution.

The external protection mechanism of knowledge depends on the legislation of intellectual property law. One issue that should be addressed is that the definitions and recognitions of property rights are different across cultures and countries. It is essential for the global community to have a common recognition toward intellectual property. Monitoring and enforcing the law according to a 'common' standard is particularly difficult. For instance, in less developed countries pirate software is cheap and easily accessible. Vendors of pirate software usually have ways to get around law enforcement. They can sell illegal copies of software online or over the telephone and ship via the post office or express courier. There is no way to monitor this illegal transaction. Why it is ineffective in deterring software pirating? The reason is that pirating software is extremely profitable. To acquire a copy of the original software may be costly, but reproduction costs are next to nothing. A blank

CD-Rom that can hold the most expensive software costs less than 50 cents a piece. The price for pirate software is usually 1/10 or less than a legal copy. Therefore, there are lots of demand for pirate software because legal copies are much more expensive. I believe if the software pricing strategy is somewhat revised, it will more effectively deter the software piracy. But it turns on the question what is the correct price level so everyone can afford to purchase a legal copy. The initial cost of producing software is very high because the software companies have to raise revenue to meet its administration, equipments and programmers expenses. If a software company can only earn 'normal profit' that only meets its expenses, there is simply no motivation for the firm to create better products.

Furthermore, some have argued that strong property rights might have a negative effect (Nelson and Romer, 1996) in preventing the flow of knowledge and technologies; it may reduce the total social welfare counting the globe as a whole. For example, if someone is able to patent a key piece of a concept or technology, under strong property rights he would be able to deter the continuing researches that need that key piece. The whole system of new technology will halt due to the patent. Hence, how property rights are defined and to what extent they should be protected needs more attention in future research.

The Creation of the Knowledge Capital

Before I explain the theory of creation of knowledge capital, it is important to clarify between the terms "Information" and "Knowledge". Although those two terms have been used interchangeably, they have distinguishable differences. As Machulp (1983) pointed out, information is a flow of messages or meanings which might add to, restructure or change knowledge. Nonaka (1994) explained it this way: information is a flow of messages, while knowledge is created and organized by the very flow of information, anchored on the commitment and beliefs of its holder. In other words, information is combinations of symbols, texts, messages, sounds, images, taste, smells or senses. Un-ordered information may or may not necessarily carry meanings. Only certain types of combinations may mean something to some certain audiences. For example, the combination of o-n-e means one, single, unpaired, unified, etc. However, the combination of o-e-n does not mean anything in English. Only people who have before learned alphabets and the meaning of each combination, which is the 'knowledge' of English, Spanish, Italian or other languages that use Alphabets, know how to decipher and decode the meaning the information conveys. After receiving the stimulations and inputs in the human brain, 'information' gets digested and converted in 'knowledge creating processes' to useful meanings or representations. That is, knowledge is created based on previous knowledge and new inputs of information. The reverse process also holds true for creating information. The creation of information starts with the existing knowledge in the human brain. People with knowledge of the combination of information could mean or imply something to others. S/he then can convert a piece of thought or knowledge in his/her brain back to a combination of symbols, texts, messages, sounds, images, taste, smells, etc., to convey his/her thinking to others. The process of reversing knowledge to information is commonly referred as 'codification' or 'externalization' of knowledge.

As I have pointed out earlier, Nonaka has classified knowledge as two dimensions -- "tacit" and "explicit". The dichotomous classification was based on Polanyi's (1958,1966) studies. He believes "explicit" or codified knowledge can be referred to as knowledge that can be transmitted in formal, systematic language. On the other hand, tacit knowledge has a personal quality which makes it hard to formalize and communicate. Bateson (1973) refers to tacit knowledge as a continuous activity of knowing and embodying. He put it this way: “Tacit knowledge has an “analogue” quality. Communication between individuals can be seen as an analogue process that aims to share tacit knowledge in order to build mutual understanding.” And the “explicit” knowledge, on the other hand, has a “digital” quality. The digital quality captures the records of the past such as libraries, archives, and databases. In short, most scholars refer to explicit knowledge as knowledge that is easy to put into words, and tacit knowledge as knowledge that is difficult to put into words for others to understand. I shall make an addition to the common definition of tacit and explicit knowledge at this point; I believe knowledge should not be referred to just dichotomous classification, it should be referred to as a degree of ‘explicit-ness” or a degree of “tacit-ness’. Knowledge includes not only the knowledge that can be transmitted in language, but also the other forms that are combinations of one or more communication and information transferring mechanisms -- gesture, language, sounds, images, taste or even senses. Before the human race invented the concept of language, our ancestors were teaching their children how to light a fire by demonstration which is a combination of the signals I pointed out above. This method is still being used by us today to teach our children how to light a campfire as well. Why does this fire-lighting knowledge pass from generation to generation with or without language? My point is that explicit knowledge does not necessary take place in the form of formal language. Knowledge can be embedded in other forms of communication. The more combinations one can use in the process of externalizing knowledge from one's brain, the more effective for the information recipients in understanding the content and the more explicit the knowledge is.

Among the economic literatures there were not many have mentioned knowledge as an important part of the economy. Needless to say, fewer people have developed theories and models to analyze the important role knowledge plays in our economy. One of the important articles in the knowledge economic literature was published Nonaka (1994). He created a dynamic model of knowledge creation in his paper. He then published several consecutive papers to shape the model. His model has been received with great enthusiasm in the business administration field. Many of papers about knowledge management cited heavily from his papers. His model was the first model in the business field to study "knowledge creation" in systemic science terms. I think it is important to introduce his model in my dissertation with some economic aspects. As I have said earlier, Nonaka assumed that knowledge is created through the conversion from tacit and explicit knowledge, such that four different modes of knowledge creation were proposed by him: First, from tacit knowledge to tacit knowledge, second, from explicit knowledge to explicit knowledge, third, from tacit knowledge to explicit knowledge and forth, from explicit knowledge to tacit knowledge. (See Figure 1.1)

Figure 1.1

Modes of Knowledge Creation

from \ to	Tacit Knolwdge	Explicit Knolwdge
Tacit Knolwedge	Socialization	Externalization
Explicit Knowledge	Internalization	Combination

Adopted from Nonaka, 1994

From the figure we can see Nonaka regards the first mode of conversion which is from tacit knowledge to tacit knowledge as 'socialization'. What he basically means is that people accumulate experiences while they 'associate' or 'socialize' with others. 'Experience' is the key to the tacit knowledge. For example, as an apprentice works with his master they 'socialize' together, and the apprentice acquires experience as he works. There is not necessarily some form of direct communication involved in 'socialization'. However, as I said earlier there might not be communication as explicit as language or written text, but there could be some combination of other different types of communication involved such as image, touch, smell, sound, and other senses etc., as people become socialized. The experiences transmit through these communication mediums when people socialize, and the experiences are being converted to tacit knowledge.

Nonaka described the second mode of knowledge conversion which is from explicit to explicit knowledge as a ‘combination’. What he meant was people exchange knowledge through explicit forms of communication and articulate new knowledge by combining these information inputs. That is, new knowledge can be created by adding, sequencing, re-ordering, sorting and re-categorizing existing explicit knowledge.

The third mode of conversion is from tacit knowledge to explicit knowledge. Nonaka stated it as ‘externalization’ – as externalizing the internal, tacit knowledge. The best analogies to describe the externalization of tacit knowledge are ‘to write a book’, ‘to make a speech’, or ‘to teach a student’. These activities all involve the codification of the tacit knowledge to an explicit form of communication.

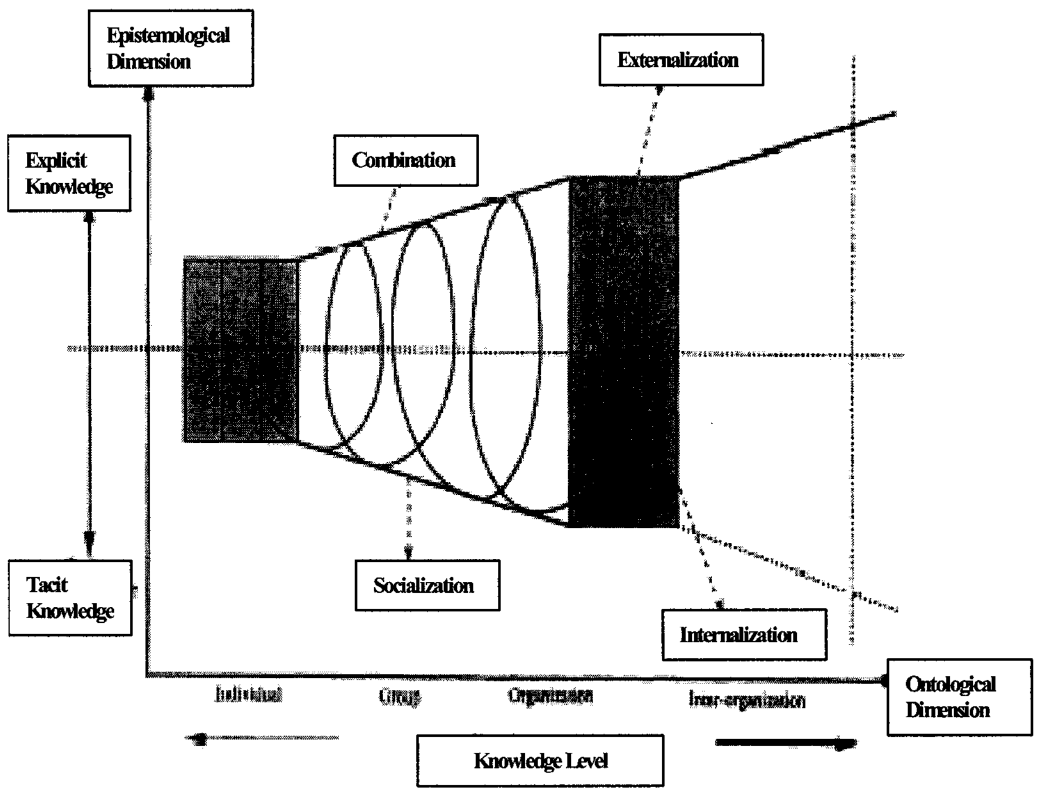
The fourth mode of conversion is from explicit knowledge to tacit knowledge. Nonaka names this process as ‘internalization’ – as the opposite of the ‘externalization’ of the third mode. The best analogy to describe the fourth mode of knowledge conversion is ‘learning’ – as ‘reading a book’ or ‘learning from a teacher’. As people learn they can absorb the information, the externalized tacit knowledge from the teacher or a book, and internalize this information into his/her own tacit knowledge. At this point Nonaka did not go any further to describe the level of learning – which I see as how well a person could ‘internalize’ the ‘external information’. I would like to add to Nonaka’s fourth mode by combining it with the Bloom’s Taxonomy (Bloom, 1959). Bloom’s Taxonomy is a well established standard in the field of education to describe the level of student learning. I describe Bloom's Taxonomy as the following levels:

1. Knowing – is the first level of learning. The learner acknowledges the information received, and would be able to arrange, define, duplicate, list, order or recall the information.
2. Comprehension – at this level the learner is able to comprehend the information and convert it to knowledge. He/she would be able to classify, describe, identify, locate and report the learned knowledge.
3. Application – at this level the learner is able to apply the knowledge learned to practical use. He/she would be able to demonstrate, solve, use or apply the knowledge.
4. Analysis – at this level the learner is able to analyze the situation connected to the knowledge learned. He/she would be able to analyze, calculate, categorize, compare, contrast, differentiate, distinguish or test the knowledge.
5. Evaluation – at this level the learner is able to evaluate the content of the knowledge learned. He/she would be able to argue, challenge, defend, judge, rate, select or value the knowledge he has learned.
6. Synthesis – at this level the learner would be able to synthesize new knowledge based on the knowledge learned. He/she would be able to create, compose, construct, design, integrate or propose new knowledge.

I altered the order in the fifth and sixth level of learning in Bloom's Taxonomy in order to be consistent with Nonaka's model. In this context the depth of learning increases as one's ability to externalize the learned knowledge increases. And according to Nonaka's theory, the key to creation and accumulation of knowledge lies between the interaction and iteration of these processes in combination of all four modes of knowledge conversion. He put it this way,

> "While tacit knowledge held by individuals may lie at the heart of the knowledge creating process, realizing the practical benefits of that knowledge centers on its externalization and amplification through dynamic interactions between all four modes of knowledge conversion. Tacit knowledge is thus mobilized through a dynamic entangling of the different modes of knowledge conversion in a process which will be referred to as a "spiral model of knowledge creation." (See Figure 1.2)

Figure 1.2 Spiral Model of Knowledge Creation



Adopted from Nonaka, 1994

Knowledge Capitalism

The term "knowledge capital" is defined as the stock of knowledge and skill, embodied in an individual or organization as a result of education, training, and experience that makes them more productive. An economy that is based on knowledge, rather than the traditional form of capital, can be called knowledge capitalism. Capitalism, in the past few hundred years, thrived on capital accumulation, open market competition, free trade, the power of the individual, and the survival of the fittest, is the most known economic principle in the western world. Unlike the traditional capitalism that is centered on the supply and demand of financial risk capital, knowledge capitalism is centered on the supply and demand of knowledge. However, knowledge capitalism shares many similar features with traditional capitalism such as characteristics of accumulation, competition, free trade and survival of the fittest. It is likely that knowledge capitalism shall co-exist with traditional capitalism in the economic system. The current trend towards a global, knowledge-based economy suggests that the mixture of knowledge capitalism and traditional capitalism will create a new venue for the new economy.

"Knowledge capital", by definition, is stock of knowledge and skill, embodied in an individual as a result of education, training, and experience that makes him or her more productive (Burton-Jones, 1999). Thus knowledge capital is embodied in the entire population of an economy. From a firm's perspective, knowledge capital can be seen as the company's corporate culture, management style, know-how, research achievement, collection of specialists, market information and other "software" type assets. The firm's knowledge capital accumulates from the input of every knowledge worker of the firm. For example, a good corporate culture could bring a positive image to the firm; it could enhance the operation's efficiency, and it could attract more talented people to join the firm. A company's trade-secrets, know-how, patents and research results are the important keys to the company's competitiveness in the market. Although it is difficult to measure the value of knowledge asset, they are not less important than the tangible assets of a firm. Good managers should know how to capitalize and benefit from the knowledge capital generated from their knowledge workers.

From a state's perspective, the importance of knowledge is essential to its social stability, economic performance and development, citizen's welfare, military prowess and its prestige among other nations. The culture, tradition, history, technology and people's education can be seen as the state's knowledge capital. People are the most fundamental unit of a society. The knowledge accumulated in each individual becomes an asset for the society. The integration and interaction of people produces a society's culture, tradition and history, and hence the state's knowledge capital. Therefore, in addition to "hardware" type construction and development, accumulation and developing "software" type knowledge capital is equally important to a state. Bringing up the national education level by providing citizens with good education resources should be one of the objectives to raise the knowledge capital embedded in the citizenry. Providing a stable and secure working environment where workers can apply their knowledge can be the state's strategy to promote creation and diffusion of new knowledge and new technology. Empirical evidence indicates that all the developed countries show a high level of average education and a low illiteracy rate – in contrast to less developed countries Carnoy and Castells, 1997). In addition, the R&D spending in all member countries of OECD (Organisation for Economic Co-

Operation and Development) is much higher than those in developing countries. These data suggest that knowledge is one important factor to social and economic development (Stevens, 1996).

Economic Growth, Productivity and Knowledge Capital

Does the U.S. gain in knowledge productivity and lose in physical productivity? Many economists have argued that there are strong relationships between technological advance, productivity growth and economic growth. First there must be a major innovation in the industry that contributes to productivity growth and then to economic growth. And technological advance is a result of accumulation of knowledge and collective knowledge works. In the past decades, the U.S. seemed to benefit from the "productivity gain-economic boom" regime until recently. As Heilbroner and Thurow (1994) pointed out, "...the Americans have lost their own place because we have suffered a decline in productivity compared with our Western allies" (Page 36). The industrial productivity rose about two percent per year in West Germany and three percent per year in Japan while it rose only less than one percent in the U.S. in the 1980s (Gordon, 1987). That was not the most serious case at all, the productivity actually fell during a good years of economic growth between 1985 and 1990. Gordon (1987), also indicated the productivity slowdown has persisted in the U.S. largely outside of manufacturing, communications, and agriculture. This problem concerns the policy makers and economists. Can the U.S. sustain economic growth while losing productivity in the long run?

There are four major reasons causing the productivity slowdown in the U.S. First, 75 percent of all employees work in some kind of service industry today, that is three times of the 1950's level. The productivity and output of the service workers was not measured correctly because the knowledge work, which is often categorized as 'service', was not measured in the economic system (Howitt, 1996). Second, the American businesses emphasize too much on short-run. European and Japanese firms planned long-term growth while the U.S. concentrated on short-term profit outcomes (Nelson, 1981; Heilbroner and Thurow, 1994). The R&D results usually do not show up in the short run. When firms lay off people for bad short-run performance and abandon their knowledge work, firms lose their accumulated organization knowledge capital and the knowledge embedded in their workers (Argote, Beckman and Epple, 1990). More or less, it will cause the loss of productivity of firms in the long run as firms have to retrain and rebuild their knowledge bases and human capital after recovery from a recession. Third was the rise of the mass labor market in Asia such as China and India. Because of the low labor cost in these markets, many U.S.-based labor-intensive manufacturers moved their production facilities to these areas. The U.S. domestic demand for low skilled labor decreased. Manufacturers staying in the U.S. did not need higher productivity to satisfy domestic demand because they rely on foreign suppliers to OEM their products. Fourth, according to the Solow's growth model an economy grow in a diminishing rate toward the steady state (Solow, 1988). Such that, the closer the economy to a steady state the more significant slow down in productivity it will be.

Others have argued that the holdup in the scientific research and innovation in the private and manufacturing sectors was one of the main cause of economic growth slowdown. Nelson and Romer (1996) mentioned that the technological dominance in the U.S. of the post-WWII era was due to two reasons. First, R&D in universities and research institutes was heavily funded. Thus, it made the U.S. the most advanced and most productive research center in almost all fields of science. It follows that U.S. industries benefited from the access to a large pool of well-trained engineers and their knowledge work. It kept the U.S. industries ahead of their major international competitors for many decades (Nelson and Romer, 1996). Second, the U.S. has been successful in the 'marketization' of technologies and their applications. For example, the microwave oven was a technology that converted from military purpose research. Usually it yielded good returns on R&D investment and thus encouraged further investment to the R&D. And as a result, the U.S. ratio of industry R&D to GDP was far higher than in any other country. Such success gave the U.S. a commanding position in the high-tech fields such as computers, semiconductors, aircraft and pharmaceuticals (Nelson and Romer, 1996). What concerned many economists is that the R&D to GDP ratio was dropping rapidly in the past few decades. The U.S. no longer kept its leading position in R&D expenditures (Gordon, 1987; Heilbroner and Thurow, 1994).

The Uncertainty of Technology and Knowledge

Why do two firms using the same technology have different outcomes, one resulting in success, the other in failure? This question could be answered by the uncertainty of knowledge creation and technological innovation. If we could predict the path of technology with certainty, there would not be a debate about the IT productivity paradox. Rosenberg (1996) pointed out the five most important uncertainties regarding technological innovation and knowledge creation that are worth our attention. First, new knowledge and new technology come into the world in a primitive condition. Their usefulness often cannot be immediately appreciated. Consequently, their perceived value is uncertain. Second, the impact of an innovation depends not only on improvements of such invention, but also on the invention of complementary invention. Third, major innovations in technology often result in entire new technological system change. However, it is extremely difficult to conceptualize the entire new system. Innovators usually think of the new innovation as a replacement of existing old technology or knowledge, and this is likely to affect the development of the entire new technological regime. Fourth, a major innovation is often found to have its origin in the attempt to solve very specific, narrowly defined problems. Once the solution has been found, it turns out that the innovation does have significant impact and application in other areas that were totally unexpected. Thus, the true value of the innovation cannot be estimated accurately. Fifth, the market perception offsets the ultimate impact of new technology and knowledge innovation. If a good invention does not gain enough critical mass, it will not survive in the market. However, the invention itself could be an important step in the break through of a new technological regime.

The Measurement Problem of Knowledge Capital

The largest obstacle in the research of the knowledge economy and knowledge capital is the measurement problem. As often mentioned we are in the knowledge age and it appears that knowledge is more important than it was in the past. The question is, how do we measure it and measure it more accurately?

> "The existing methods and concepts of accounting, budgeting and planning are biased against anything that is not a tangible asset. Many prior attempts to calculate the productivity of "information" have foundered on the reluctance of the current stakeholders to be subjected to the sort of measurements that were previously reserved only for the laboring classes." (Strassmann, 1988).

In the modern scientific research method we look for a solid theory, clearly defined data and controllable variables to explain what was not explained before. In the research in knowledge economics and information science the measurement problem often troubles researchers. The collection of data is difficult and the accuracy of data is questionable. Human factors make controllable variables uncontrollable. Ever changing assumptions and presumptions make theoretical ground unsound.

Stigler (1973) indicated the problems of moral hazard and adverse selection are unavoidable, and the problems are particularly intractable when "tacit" knowledge is being exchanged. Since tacit knowledge is hard to codify, to monitor the exchange between types of knowledge is extremely difficult. For example, a student and a teacher engage in the knowledge transfer activity 'teaching'. A third person can not correctly judge what and how much of the knowledge has been transferred between the student and teacher. Nevertheless, only to a certain extent, external instruments such as exams or student performance evaluation can verify knowledge transfer. Howitt (1996) pointed out that when the object being exchanged is knowledge, the resource cost incurred by the seller need not include a sacrifice of his or her own command over the object. This creates a problem in measuring the knowledge. Hence he identified four major measurement problems that distinguish knowledge good exchange from capital good exchange. First is the "knowledge-input problem". The amount of resources devoted to the creation of knowledge is underestimated in current R&D activity and in resources used in the educational and academic sector:

Much of the costs are internalized by individuals. Second is the "knowledge-investment problem." The knowledge output gained from formal and informal R&D activities is typically not measured, because it does not immediately reflect in the market as a commodity with a price. Third is the "quality improvement problem." Knowledge creation that results in firms improving goods and services often goes unmeasured. The difficulty is the construction of price indexes that deal with new goods and quality improvements. Fourth is the "obsolescence problem." The creation of new knowledge also accounts for the depreciating of physical capital. The timing and extent of replacement investment are endogenous variables that the national income accountant can only capture in rough measure by applying simple mechanical formulas. Furthermore, the accounting for obsolescence becomes even more problematic when innovations accelerate the rate of obsolescence of old knowledge and capital.

Bohn (1994) offered a framework for measuring the knowledge in a business management perspective. He emphasized the firm specific and procedure knowledge within an organization. He identified knowledge as having eight stages from complete ignorance to complete knowledge. The ranking orders are from non-existence of knowledge to tacit knowledge and to the degree of explicitness of knowledge that can be written or expressed in formulas or algorithms. His proposition is that technological knowledge is defined as understanding the effects of the input variables on the output, such that, the process output Y is an unknown function f of the inputs x. That is $Y=f(x)$. He investigated what kind of input at what stage of knowledge would lead to what kind of output – an input-output analysis. However, the problem is that the functional form cannot be specified to a more explanatory extent and consequently resulting output may differ from case to case. Due to the fact that factors that embed knowledge in a person are different and not explicit, the most important variable investigated, "human knowledge", cannot be controlled. Although his work might not be effective in measuring the "tacit" side of knowledge capital in a business organization, it is theoretically workable in measuring explicit knowledge which is more transparent and controllable.

Empirical Evidences in the Knowledge Capital

The research on organizational learning dates to Wright's work in 1936. He proposed studies of organizational learning curve and the functional form of the relationship between unit cost and cumulative output. Following his work, many researchers have contributed to the on-going research regarding the organizational learning and accumulation of knowledge. The presence of the learning curve in manufacturing various products has been documented in Yelle (1979), Dutton and Thomas (1984), Hayes and Clark (1986), Argote and Epple (1990). Rapping (1965) has shown convincing evidence of "learning by doing" at the organization level by using data from producing the Liberty Ship during WWII. Following Rapping's work, Epple and Argote (1991) extended the research by adding the factor of forgetting. They pointed out that the forgetting factor negates the effect of organizational learning to a certain degree. So its importance should not be overlooked.

Much research on organizational level learning have tried to solve the puzzle of productivity growth. Many researchers believed that the puzzle could be solved by characterizing the learning behavior and relating it to cumulative output. And as a result, much evidence has shown that knowledge has been embedded partly in the production equipment in terms of technology, and partly embedded in the workers in terms of experience and knowledge of specific production processes. Firms that enter the market later than their counterparts with earlier market entrance actually have higher productivity due to utilizing newer production technologies and employing more experienced workers in the industry pool. Yet the learning rate varies across organizations and industries. The transfer of knowledge across organizations also occurs in some industries through personnel movement, communication, forums, meetings, modifying of technology, reverse engineering, training and various inter-organizational activities. Zimmerman (1982) found evidence of learning and knowledge transfer in the construction of nuclear power plants. However, Jaskow and Rose (1985) found that the transfer was not statistically significant in the construction of coal burning power plants. Why do the results differ in these two similar scenarios? One possible answer to that might be the "tacitness" of knowledge to the job that involved workers and the degree of knowledge work required for certain industries. The workers constructing nuclear power plants require higher education and higher skills than the workers constructing coal-burning plants.

Epple and Agote (1990, 1991, 1994 and 1995) have carried out a series of research investigations with respect to the organizational learning curve, knowledge accumulation and transfer in different aspects. Their work in 1990 extended Rapping's 1965 work using the Liberty Ship construction data set. Besides the learning curve, learning by doing behavior appeared in their research as statistically significant. They also concluded: first, in contrast to the conventional learning curve model that assumes knowledge acquired through learning by doing does not depreciate, their finding suggests knowledge acquired in production actually depreciates rapidly. If the stock of knowledge is not to be replenished by continuing production or personal training, approximately only 3.2% would remain one year later. This result suggests that the organization or industry actually forgets. They forget the effective and efficient production processes due to the discontinuation of production and labor turnover. Experienced workers who leave would be replaced by new and less-experienced workers. Second, knowledge depreciation could also be due to technological obsolescence, loss of organization records or the relocation of plants. New production technology, new tools and equipment, or new task specific processes could also make old skills obsolete. As a result the workers experienced in older technologies have to be retrained to use new technologies. Third, their result indicates shipyards started later than earlier shipyards have higher productivity. The production knowledge was partially transferred from old shipyards to new shipyards. And fourth, their results could not identify directly where knowledge is being embedded – is it in the equipment and technologies or the workers? The result they found indicates knowledge acquired in the Liberty Ship producing program was embedded in technologies. However, the rapid depreciation of knowledge in shipyards suggests otherwise: learning and knowledge was not totally embedded in technologies. Part of it must be embedded in workers.

In order to find evidence of intra-organizational knowledge transfer, Epple and Agote have done two additional studies in the manufacturing and service industries. The former one was based on data collected from a North American truck plant that produces a single vehicle and the latter one was based on data from 36 pizza chain stores in Southwestern Pennsylvania. In the manufacturing industry study, they found learning by doing yields large productivity gains as production progresses and as knowledge is being accumulated. However, the rate of acquisition of knowledge declines as the stock of knowledge increases. Their result also indicates 69% of knowledge acquired during one-shift per day operation carried forward to two-shift per day operation in the organization. Furthermore, about 50% of the knowledge acquired on the first shift operation was being transferred to the other shift when both shifts were in operation. In comparison to their earlier Liberty Ship study, they also found that the knowledge transfer within a plant is much greater than between plants that are geographically separated.

In their study of the pizza chain industry, the result suggests the service industry demonstrated a much slower learning rate than the manufacturing industry. Knowledge transfers across stores owned by the same franchisee. However, knowledge does not transfer across stores owned by different franchisees. In addition, the knowledge embedded in technologies is more resistant to depreciation than the knowledge embedded in the workers. This causes the service industry to have a slower learning rate. Much of the knowledge acquired from learning is difficult to standardize and thus hard to make explicit. Many types of service work require interaction with customer. Under different circumstances, workers require different skills to solve problems. Thus, much of the working experiences are 'tacit' and embedded in the workers, and consequently the transfer of knowledge takes a longer time at a slower rate. The manufacturing industry, on the other hand, usually has a higher degree of labor division. Each job is more process specific. Workers in manufacturing industries usually interact with machines and equipment in their job, therefore, the working situation they faced are simpler. Most of the production processes can be documented and standardized thus making the transfer of knowledge more 'non-personal' and easier. Their research suggests that knowledge appears to be embedded more in technologies rather than in persons in the manufacturing industry. In the service industry, knowledge embeds more in persons rather than in technologies.

More recently, some European researchers also directed their efforts to studying the impact of knowledge capital in different industries. Guilhon et all (2001), identified several 'knowledge intensive' industries: chemical, bio-pharmaceutical, semiconductor and software. Their studies attended to the issue of the emerging knowledge market in these knowledge-intensive sectors. They found that knowledge is crucial for wellness in these industries and there are markets that exist for exchange and trade of knowledge and technologies.

Mariani and Cesaroni (2001) pointed out some limitations in the rise of the market of knowledge: a transactional limitation due to incomplete contracts and property rights definitions, a cognitive limitation due to context-dependent nature of knowledge, and a limitation on size and composition of the demand. In addition, to achieve economies of scale, the services provided by specialized engineering firms are crucial in the chemistry sector. Licensing proprietary technology and making it 'trade-able' provides a more profitable option to the firms concentrating heavily in R&D.

Rhuguet and Silvy (2001) pointed out that there is a generalization of abstract knowledge in the pharmaceutical sector. By allowing the fragmentation of knowledge it leads to the division of innovative labor -- knowledge creators. For example, the fragmentation of knowledge will allow some companies specialize in creating only certain types of pharmaceutical formula and improving these formulas. The company specialized in creating “pain-killer” type formula would not cross the line to create “nutrient-supplement” type formula that is specialized by other company. There is evidence of vertical division of innovative labor between the “large drug firms” (LDF) and the “dedicated biotech firms” (DBF) once the market agreements are reached between them. The horizontal division of innovative labor also shows up in the inter-DBF and inter-LDF activities. The property rights favor the market for knowledge. However, it does not work out perfectly -- many firms have to solve their cases in the courts. Many DBFs are actually OEMs for LDF. They work under contracts. However, the contract between DBF and LDF sometimes does not specify the property right of a created formula. Therefore there are frequently court cases over the ownership of new formula. Nevertheless, their study suggests that the more ‘knowledge intensive’ a sector is, the more specific division of innovative labor will be, and knowledge and information will play an increasingly important role in the globalization of economies.

Attia, Dave and Rizoulieres (2001) also made a similar conclusion in their study of the semiconductor sector. They argued that the division of specific knowledge creativity actually serves as a protective mechanism to the firms. Nevertheless, the protection is effective only to a limited extent. A more strict protective mechanism has to rely on the enforcing of property rights.

The software industry is a difficult case. It exhibits some common properties as other industries and yet it behaves differently from the other industries. The knowledge in software industry is usually regarded as clearly explicit. However, I believe the knowledge to make good software that can receive good market value is tacit to good programmers at a very high degree. That is why some good software-producing firms consist of only a dozen persons while some consist of thousands. The input of total knowledge creating labor does not have a strong relationship to the market value of the output. Despite that, Athreye (2001) pointed out that the extent of homogenous demand has defined the existence of the mass commodity software market while the heterogeneous demand characterized the niche and outsourcing software market. Standardization in software and platforms reduces the impact of heterogeneity.

So far, studies at the firm level have identified the importance of knowledge capital. I also located some macro level empirical studies that indicate the transition from an industrial-based economy to a knowledge-based economy. The empirical research uses data from OECD member countries shows evidence of technological displacement on work and jobs that has been largely ambivalent. The study shows that job opportunity is higher for higher educated and higher skilled workers. Job opportunity has significantly declined for the unskilled and poorly qualified (Carnoy and Castells, 1997). As their study suggests, one reason that caused this is the shifting of labor-intensive jobs toward Asia and other developing countries. Another study carried out by Stevens (1997) and other OECD observers shows the high-technology share of OECD manufacturing production and exports has more than doubled, reaching 20% to 25%. Knowledge intensive service sectors are growing even faster. The study estimated that more than 50% of GDP in the major OECD economies is now knowledge-based. The demand for more highly educated workers is growing in the OECD member countries. The average unemployment rate is 10.5% for people with a lower-secondary education, and is 3.8% for people with an university level education. These studies indicate the shifting from an industrial-based economy to a knowledge-based economy in the advanced countries. It is commonly observed that the exports in more technological advanced countries have become more of the technologies themselves. It implies that selling technologies is more cost-effective than manufacturing goods. From a long term point of view, producing goods is subject to the risk of long-term economic volatility; selling technologies is not. Japan is the first case in Asian countries for exporting their "knowledge goods". They imported a large portion of production technologies from the U.S. and West Germany between the 1950s and 1970s. After rapid economic growth during that period, Japan positioned itself among the world's top economies. The Japanese became technology exporters after the 1970s – they exported their knowledge, experiences and technologies to their neighboring countries such as Taiwan, Korea and China. Following the Japanese experience, it has been observed that recently Taiwan and Korea have started to export their technologies to less developed countries. For example, many silicon chip fabrication plants and computer hard disk manufacturing plants have migrated from Taiwan and Korea to countries such as China, Indonesia, Vietnam and Malaysia. The implications here are two-fold: First, switching of heavy industry to a knowledge-based technological industry in developed countries and, second, importation and transfer of knowledge and technologies are necessary to facilitate faster economic growth in less developed countries because it is often faster to buy than to develop the technologies. In other words, building-up of the knowledge capital in these advanced countries has reached a saturation point that can benefit from exportation, or otherwise the over building-up of knowledge capital will idle. The knowledge and technologies being exported can actually be better priced and better used in the countries that have higher need for the knowledge and technologies. This also implies that the marginal productivity of knowledge capital is larger in less developed countries than developed countries.

From the literatures I have reviewed I have not found a good model that characterizes the flow of knowledge capital at individual level or at organizational level. I believe formal mathematical modeling can be helpful in understanding the nature of knowledge capital accumulation and transfer at individual level, or to a greater extent, it can also capture the behavior of research and development investment at organizational level. Therefore, I decide to create a model that can provide better insight and establish a more solid theoretical background to academia and businesses for further research in the field of knowledge economics.

Chapter 2

In this chapter I construct mathematical models for knowledge capital accumulation and transfer based on economic principles. I attempt to establish the microeconomic theoretical ground for analyzing knowledge capital. There is never a single model that can perfectly describe the world. All models are subject to criticism under different assumptions. However, by logically and systemically modeling, we probably can better understand what role knowledge capital play in our economy. First, I start from the Individual Choice of Knowledge Capital Model based on intuitive and logical assumptions that an individual works and gains experience and wages. The individual, also can be called as an 'agent', faces time constraints, budget constraints and pay for his or her living and educational expenses. Under such conditions I model how an individual chooses the amount of education and amount of work (both related to knowledge stock accumulation) while maximizing his or her utility. I further extend my model to an overlapping generation model. The model reveals the dynamic of knowledge capital accumulation and the transfer from generation to generation.

The Individual Choice Model

[model 1.1]

I define knowledge capital ($\hat{q}$) as:

$$(1) \qquad \hat{q} = f(\text{education,experience})$$

Experience can be acquired by working and converting to knowledge at a rate t per hour worked. Such that:

Experience = ΦH H is the hours worked

Where $\Phi > 0$

Education can be acquired by receiving education and studying, and is converted to knowledge at rate p per hour of education received or studied. Such that:

Education = Ωedu edu is the hours education received

Where $\Omega > 0$.

So the knowledge capital the agent has can be written as follows:

$$(2) \qquad \hat{q} = \Phi H + \Omega edu$$

The time constraint an agent faces is:

$$(3) \qquad 1 \geq edu + H + L$$

The agent's total time is spent to H, hours worked, and edu, hours education received, and L, hours of leisure. The total hours normalize to one.

The agent works and receives salaries. I assume that wage rate can be represented as follows:

$$(4) \qquad \hat{W} = w(1+\hat{q}) \qquad w > 0 \ , \ \hat{q} > 0$$

($\hat{W}$) is agent's wage rate. It is based on the average wage rate (w) and agent's knowledge stock ($\hat{q}$).

An agent faces budget constraints and decides how to allocate his/her monetary resources. For simplicity, I say that an agent's earnings are spent only on consumption and educational expenses. The consumption (C) here is a lump sum consumption that includes all expenses except education costs. So that,

(5) $\hat{W}H \geq C + \pi edu$ Where $\pi > 0$.

π is the average rate per hour of educational cost such that (πedu) is the total educational expenses the agent would spend.

The agent's utility function is assumed as Cobb-Douglass form:

(6) $U = U(C, H, L, edu) = C^x L^y q^z$

Where $x + y + z = 1$ and $x,y,z > 0$.

From the above conditions, the model can be constructed as follows:

Max $U = U(C, H, L, edu) = C^x L^y q^z$

S.T. $\hat{W}H \geq C + \pi edu$

$1 \geq edu + H + L$

where $\hat{W} = w(1 + \hat{q})$

$\hat{q} = \Phi H + \Omega edu$

I set up the Lagranian equation as follows to solve the agent's utility maximization problem.

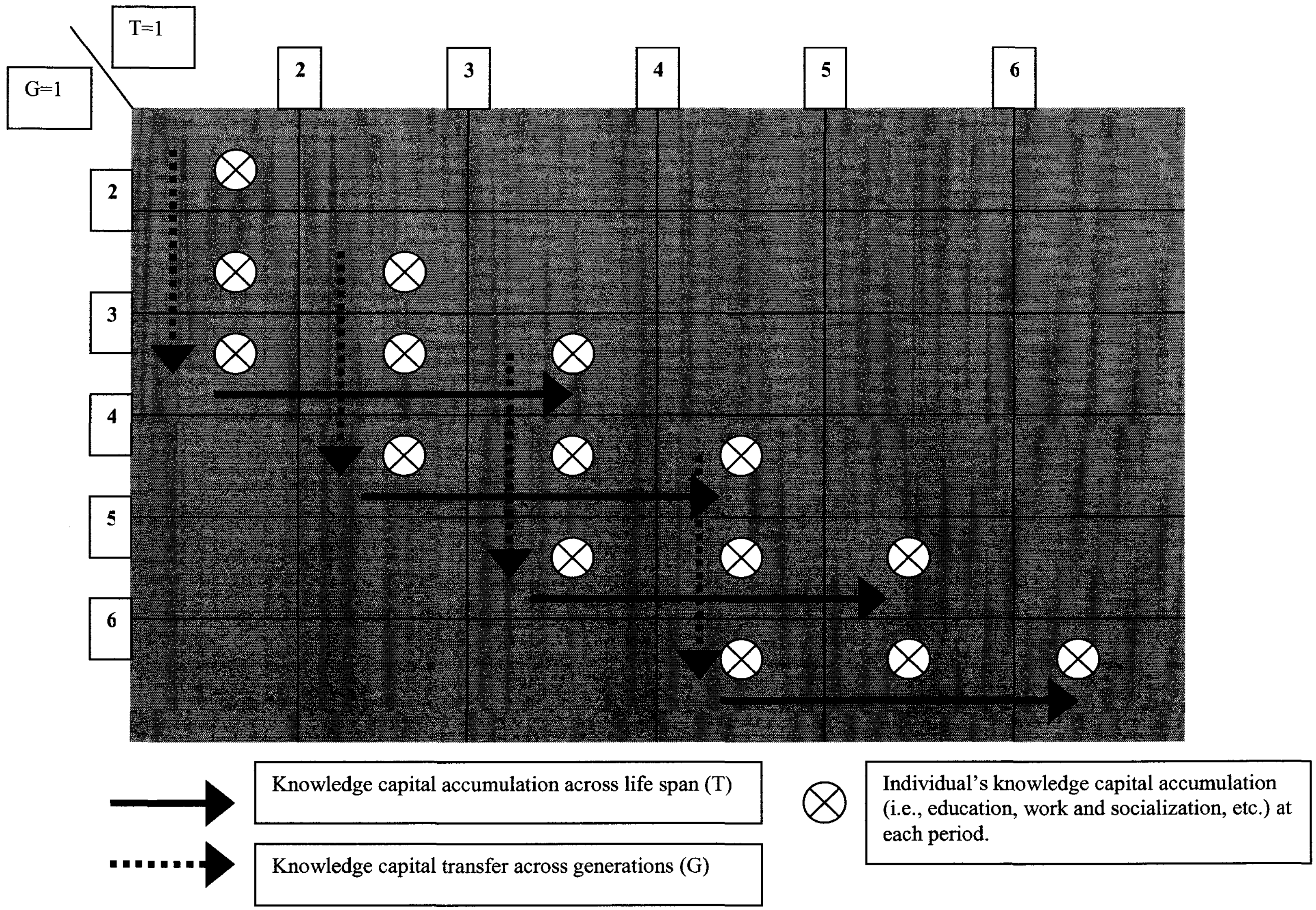
(7) $V = C^x L^y q^z - \lambda_1 (C + \pi edu - w(1 + \Phi H + \Omega edu)H) - \lambda_2 (edu + H + L - 1)$

Results can be found for this specific model. These results yield some implications. First, the lower the education cost, the higher incentive for the agent to acquire and accumulate knowledge capital that would reflect on his/her wage function. This suggests that public funding or government intervention to keep educational costs down may be beneficial to economic growth and social stability. Second, the knowledge accumulation through further education or on-the-job training shall boost agent's wage rate. Third, when average income is high, people seem to have less incentive to pursue higher education; they can acquire skills from work rather than go to school.

The problem of the individual's choice model is it does not describe the dynamic of knowledge capital accumulation and transfer. However, it establishes the characteristics of the optimal allocation of individual's work hours, education hours and leisure hours. Now I extend the individual model to a three-period overlapping generation model that could better characterize an agent's optimization choices of knowledge capital accumulation and transfer in between the agent's families.

Figure 2.1 is a graphical representation of the multi period overlapping generation model. In the figure, the dynamic of knowledge accumulation and transfer for an agent in his/her family is illustrated. The horizontal axis represents time period, and the perpendicular axis represents generation. So block (1 -- time period, 3 -- generation) is read as generation three at time period one. At block (1,3) the agent is at childhood and s/he accumulates knowledge by having education and receiving knowledge from the parents and grandparents. The dotted arrow represents the transfer of knowledge from parent (1,2) and grandparent generations (1,1) to the child generation (1,3). As time progresses, generation (1,3) grown up and advances to block (2,3). At block (2,3) the agent now becomes a parent and his/her offspring enters at block (2,4). At this period the agent accumulates knowledge by having education, working, socializing and receive some knowledge transferred from his/her parent generation which is now a grandparent generation. S/he also transfers part of the knowledge to the young generation at (2,4). As time progresses one more period, generation (2,3) advances to (3,3). The agent retires at period (3,3) and is grandparent generation. At (3,3) the individual does not work, however, s/he still can accumulate knowledge in various ways. The knowledge the agent accumulates through his/her lifetime is represented by the solid arrow line. S/he also transfers part of the knowledge s/he accumulates through life to the offspring generations (4,3) and (5,3).

Figure 2.1 Graph Representation of Multi Generation Overlapping Knowledge Capital transfer and accumulation Model



The Three Period Overlapping Generation Model of Knowledge Capital [model 2.1]

In the overlapping generation model I assume that:

Agents are forward looking.

Agents receive education during the first period (when they are youngsters).

Agents work during the second period (when they are adults).

Agents retire in the third period and live on savings (when they are elders).

There is no bequest from an elder agent to younger agent.

There is no population growth.

Discount factor for knowledge is ignored.

The budget constraint for agent i at time t is:

$$\hat{W}_t^i H_t^i \geq C_t^i + S_t^i + \pi^{i+1} edu_t^{i+1} \tag{8}$$

Where $\hat{W}_t^i$ is agent i's wage rate at time t, H_t^i is agent i's working hours at time t, C_t^i is agent i's consumption at time t, S_t^i is agent i's saving at time t, π^{i+1} is agent i+1's average hourly education cost and edu_t^{i+1} is agent i+1's education time at time t. So, equation (8) states that agent i's total income at time t is spent on consumption, saving and children's education costs.

The saving function for agent i is:

$$R_{t+1} S_t^i \geq C_{t+1}^i \tag{9}$$

Since agent i retires at period t+1 and lives on savings, equation (9) states that the savings of agent i at time t times interest rate R_{t+1} will be agent i's total consumption at period t+1.

I combine (8) and (9) to obtain a life cycle budget constraint:

(10) $$R_{t+1}\left[\hat{W}_t^i H_t^i - C_t^i - \pi^{i+1} edu_t^{i+1}\right] \geq C_{t+1}^i$$

The time constraint for agent i is:

(11) $1 \geq edu_{t-1}^i$ agent i is a youngster and receives education only.

(12) $1 \geq H_t^i$ agent i is an adult and works only.

(13) $1 \geq L_{t+1}^i$ agent i is an elder and is retired, where L_{t+1}^i is leisure time.

I combine (11),(12) and (13) to obtain a life cycle time constraint:

(14) $$1 \geq edu_{t-1}^i + H_t^i + L_{t+1}^i$$

So equation (14) states that agent i's total life time is allocated to education at t-1 period, work at t period and leisure at t+1 period.

I assume the wage rate function is:

(15) $$\hat{W}_t^i = W_t(1+\hat{q}_t^i)$$

Where W_t is the average wage rate at time t. So that, the wage rate of agent i depends on his/her knowledge capital level. And knowledge capital is defined as:

(16) $$\hat{q}_t^i = f(exp^i, edu^i)$$

Agent i gains some experience from every hour of work and is converted to knowledge by rate Φ where $\Phi > 0$. So,

(17) $$exp = \Phi H$$

Every hour of education received by agent i is converted to knowledge by rate Ω where $\Omega > 0$. So,

(18) $$edu = \Omega\, edu$$

Therefore,

(19) $$\hat{q}^i = \Phi^i H^i + \Omega^i edu^i_{t-1}$$

Φ^i and Ω^i can be interpreted as agent *i*'s efficiency coefficients (or intelligence) for studying and working.

For simplicity I assume that Φ^i and Ω^i are constant over time, but can be different from agent to agent.

The utility function of agent *i* is represented by:

(20) $$U^i_t = U^i_t\left(C^i_t, C^i_{t+1}, edu^i_{t-1}, H^i_t, L^i_{t+1}, edu^{i+1}_t\right)$$

The utility maximization problem for agent i can be described as follows:

(21) $$MaxU^i = U^i + \beta^i U^{i+1*}$$

Subject to the life cycle budget constraint and life cycle time constraint:

(22) $$C_{t+1} - R_{t+1}[W_t H^i_t(1 + \Phi^i H^i_t + \Omega^i edu^i_{t-1}) - C_t - \pi^{i+1} edu^{i+1}_t] \le 0$$

(23) $$edu^i_{t-1} + H^i_t + L^i_{t+1} \le 1$$

Where U^{i+1*} is the children's utility, and

$\beta^i > 0$ if agent i loves children

$\beta^i < 0$ if agent i dislikes children

So agent i acquires some utility from his/her children if s/he likes them. On the other hand, s/he might get disutility from children if s/he thinks children are a burden.

Assuming the Inada condition holds, then according to the Kuhn-Tucker condition we can solve the utility maximization problem for agent i with the Lagrangian equation.

$$(24)\qquad V = [U^i + \beta^i U^{i+1}] - \lambda_1[C_{t+1} - R_{t+1}[W_t H_t^i(1+\Phi^i H_t^i + \Omega^i edu_{t-1}^i)$$
$$-C_t - \pi^{i+1} edu_t^{i+1}]] - \lambda_2[edu_{t-1}^i + H_t^i + L_{t+1}^i - 1]$$

The Lagrangian multipliers λ_1 and λ_2 are non-negative.

So I obtain the first order conditions as following.

$$(25)\qquad \frac{dV}{dC_t} = U_{Ct}^{i\,\prime} - \lambda_1 R_{t+1} = 0$$

$$(26)\qquad \frac{dV}{dC_{t+1}} = U_{Ct+1}^{i\,\prime} - \lambda_1 = 0$$

$$(27)\qquad \frac{dV}{dedu_{t-1}^i} = U_{edu_{t-1}^i}^{i\,\prime} + \lambda_1(R_{t+1} W_t H_t^i \Omega^i) - \lambda_2 = 0$$

$$(28)\qquad \frac{dV}{dH_t^i} = U_{H_t^i}^{i\,\prime} + \lambda_1(R_{t+1} W_t(1 + 2\Phi^i H_t^i + \Omega^i edu_{t-1}^i) - \lambda_2 = 0$$

$$(29)\qquad \frac{dV}{dL_{t+1}^1} = U_{L_{t+1}^i}^{i\,\prime} - \lambda_2 = 0$$

$$(30)\qquad \frac{dV}{dedu_t^{i+1}} = U_{edu_t^{i+1}}^{i\,\prime} + \beta^i U_{edu_t^{i+1}}^{i+1\,\prime} - \lambda_1(R_{t+1}\pi^{i+1}) = 0$$

$$(31)\qquad \frac{dV}{d\lambda_1} = C_{t+1} - R_{t+1}[W_t H_t^i(1 + \Phi^i H_t^i + \Omega^i edu_{t-1}^i) - C_t - \pi^{i+1} edu_t^{i+1}] = 0$$

$$(32)\qquad \frac{dV}{d\lambda_2} = edu_{t-1}^i + H_t^i + L_{t+1}^i - 1 = 0$$

There are six choice variables in the system and two Lagrangian multipliers as unknowns, and there are eight first order condition equations. So solutions for all the variables can be found. At this point I skip the solutions for the choice variable since I am most interested is the comparative statics of the model because they show how agent changes his/her choices when parameter changes.

The following comparative statics can be derived by taking partial derivatives of the first order conditions with respect to the desired parameters. So,

$\frac{\partial C_t}{\partial R_{t+1}} > 0$ If agent i expects the future interest rate will rise, he will expect to have more future income from saving. S/he is more likely to consume more during period t.

$\frac{\partial C_t}{\partial W_t} > 0$ When average wage rate rises, agent i becomes wealthier and chooses to consume more during period t.

$\frac{\partial C_t}{\partial \pi^{i+1}} < 0$ When children's education expenses increase, agent i would choose to consume less during period t because s/he has to allow more budget for children's education.

$\frac{\partial edu_{t-1}^i}{\partial \Phi^i} < 0$ If agent i is more prolific at working, s/he is more likely to spend less time in receiving education during period t-1. This is due to the substitution effect that the agent can 'substitute' his/her time to a more efficient use so that agent i can accumulate knowledge faster by working rather than by studying.

$\frac{\partial edu_{t-1}^i}{\partial \Omega^i} < 0$ If agent i is more prolific at studying, s/he is more likely to spend less time in receiving education during period t-1 because s/he accumulate knowledge faster. For example, if the agent is smart, s/he probably requires less time of study to understand class material while others may have to spend more time studying.

$\frac{\partial edu_{t-1}^{i}}{\partial R_{t+1}} < 0$ If agent i expects the interest rate will rise, s/he is more likely to receive less education during period t-1. The reason is that if the agent thinks s/he will be wealthier in the future, s/he will not spend as much effort during time t studying in order to get a higher salary.

$\frac{\partial edu_{t-1}^{i}}{\partial W_{t}} < 0$ If agent i expects the average wage rate will rise, s/he is more likely to spend less time in education during period t-1 because s/he is almost certain that s/he will be wealthier regardless of education.

$\frac{\partial H_{t}^{i}}{\partial \Phi^{i}} < 0$ If agent i is more prolific at working, s/he is more likely to spend less time working during period t-1 because s/he accumulate knowledge faster. For example, if the agent is smart, s/he probably have a tacit knowledge on how to work more effectively and efficiently. Therefore, s/he needs less time to perform a task than others need.

$\frac{\partial H_{t}^{i}}{\partial \Omega^{i}} < 0$ If agent i is more prolific at studying, s/he is more likely to spend less time working during period t-1. This is due to the substitution effect that the agent can 'substitute' his/her time to a more efficient use so that agent i can accumulate knowledge faster by studying rather than by working.

$\frac{\partial H_{t}^{i}}{\partial W_{t}} < 0$ If average wage rate rises, agent i will choose to work less due to increased wealth.

$\frac{\partial H_t^i}{\partial R_{t+1}} < 0$ If interest rate rises, agent i will choose to work less because he will be wealthier with the same amount of his /her savings.

$\frac{\partial H_t^i}{\partial \pi^{i+1}} > 0$ If children's education expenses increase, agent i would choose to work more in order to pay for the higher cost.

$\frac{\partial edu_t^{i+1}}{\partial R_{t+1}} > 0$ If interest rate rises, agent i will expect to be wealthier in the future, so s/he is more likely to let his/her children receive more education.

$\frac{\partial edu_t^{i+1}}{\partial W_t} > 0$ If average wage rate rises, agent i is more likely to let children receive more education due to increased wealth.

$\frac{\partial edu_t^{i+1}}{\partial \pi^{i+1}} < 0$ If child's education expenses increases, agent i is more likely to offer the child less education.

$\frac{\partial edu_t^{i+1}}{\partial \Phi^i} > 0$ If agent i is prolific at working (or s/he is intelligent), s/he is more likely to let children receive more education.

$\frac{\partial edu_t^{i+1}}{\partial \Omega^i} > 0$ If agent i is prolific in studying (or s/he is intelligent), s/he is more likely to let children receive more education.

These last two comparative statics basically mean that smart parents are more likely to offer their children more education because they are more likely to be wealthier.

[model 2.2]

Model [2.2] is an extension of model [2.1]. I make the same assumptions in model [2.2] except that adults now work during the second period and receive further education as well. This enables the adult generation to accumulate knowledge from on-the-job training and continuing education instead of accumulating knowledge from work only. In model [2.2], I revise the budget constraint to incorporate the education costs and time constraint to incorporate education time for agent i. Otherwise, the model setup is the same as model [2.1].

So what changed in model [2.2] is,

(33) $\hat{q}^i = \Phi^i H^i + \Omega^i edu^i_{t-1} + \Omega^i edu^i_t$

Agent i now accumulates knowledge from first period education, second period work and second period education or on-the-job training.

I combine the budget constraint and saving function to obtain a life cycle budget constraint:

(34) $R_{t+1}\left[\hat{W}^i_t H^i_t - C^i_t - \pi^{i+1} edu^{i+1}_t - \pi^i edu^i_t\right] \geq C^i_{t+1}$

Expending the $\hat{W}^i_t H^i_t$ term the life cycle budget constraint becomes:

(35) $R_{t+1}\left[W^i_t (1 + \Phi^i H^i_t + \Omega^i \left(edu^i_{t-1} + edu^i_t\right)) H^i_t - C^i_t - \pi^{i+1} edu^{i+1}_t - \pi^i edu^i_t\right] \geq C^i_{t+1}$

The time constraints for agent i are:

(36) $1 \geq edu^i_{t-1}$

(37) $1 \geq H^i_t + edu^i_t$

(38) $1 \geq L_{t+1}^{i}$

Combine the time constraints at each period to acquire life cycle time constraint for agent i:

(39) $1 \geq edu_{t-1}^{i} + edu_{t}^{i} + H_{t}^{i} + L_{t+1}^{i}$

The utility function of agent i is represented by:

(40) $U_{t}^{i} = U_{t}^{i}\left(C_{t}^{i}, C_{t+1}^{i}, edu_{t-1}^{i}, edu_{t}^{i}, H_{t}^{i}, L_{t+1}^{i}, edu_{t}^{i+1}\right)$

The utility maximization for agent i can be described as follows:

(41) $MaxU^{i} = U^{i} + \beta^{i} U^{i+1*}$

Subject to the life cycle budget constraint and life cycle time constraint:

(42) $C_{t+1}^{i} - R_{t+1}\left[W_{t}^{i} H_{t}^{i}(1 + \Phi^{i} H_{t}^{i} + \Omega^{i}\left(edu_{t-1}^{i} + edu_{t}^{i}\right)) - C_{t}^{i} - \pi^{i+1} edu_{t}^{i+1} - \pi^{i} edu_{t}^{i}\right] \leq 0$

(43) $edu_{t-1}^{i} + edu_{t}^{i} + H_{t}^{i} + L_{t+1}^{i} \leq 1$

Where U^{i+1*} is the children's utility, and

$\beta^{i} > 0$ if agent i loves children

$\beta^{i} < 0$ if agent i dislikes children

Assuming the Inada condition holds, then according to the Kuhn-Tucker condition, we can solve the utility maximization problem for agent i with the Lagrangian equation.

(44) $$V = [U^{i} + \beta^{i} U^{i+1}] - \lambda_{1}[C_{t+1}^{i} - R_{t+1}[W_{t}^{i} H_{t}^{i}(1 + \Phi^{i} H_{t}^{i} + \Omega^{i}\left(edu_{t-1}^{i} + edu_{t}^{i}\right))$$
$$- C_{t}^{i} - \pi^{i+1} edu_{t}^{i+1} - \pi^{i} edu_{t}^{i}] - \lambda_{2}[edu_{t-1}^{i} + edu_{t}^{i} + H_{t}^{i} + L_{t+1}^{i} - 1]$$

or (45) $$V = [U^{i} + \beta^{i} U^{i+1}] - \lambda_{1}[C_{t+1}^{i} - R_{t+1}[W_{t}^{i} H_{t}^{i}(1 + \Phi^{i} H_{t}^{i} + \Omega^{i} edu_{t-1}^{i}) - C_{t}^{i} - \pi^{i+1} edu_{t}^{i+1}]$$
$$-(R_{t+1} W_{t} H_{t}^{i} \Omega^{i} - \pi^{i}) edu_{t}^{i}] - \lambda_{2}[edu_{t-1}^{i} + edu_{t}^{i} + H_{t}^{i} + L_{t+1}^{i} - 1]$$

I acquire similar first order conditions in model [2.2] as in model [2.1]. Most results are consistent with model [2.1] except agent i's choice of first period education and second period education. Following are some useful comparative statics I obtained from model [2.2].

$\frac{\partial edu_{t-1}^{i}}{\partial \pi^{i}} > 0$ If agent i knows the education cost will be more expensive for him/her at period t, s/he is more likely to spend more time studying in period t-1.

$\frac{\partial edu_{t}^{i}}{\partial \Phi^{i}} > 0$ If $(R_{t+1}W_t H_t^i \Omega^i - \pi^i) > 0$.

$\frac{\partial edu_{t}^{i}}{\partial \Omega^{i}} > 0$ If $(R_{t+1}W_t H_t^i \Omega^i - \pi^i) > 0$.

$\frac{\partial edu_{t}^{i}}{\partial W_{t}} > 0$ If $(R_{t+1}W_t H_t^i \Omega^i - \pi^i) > 0$

The above three comparative static basically mean that agent i will choose more second period education only if the education cost is less than average salary times agent i's education efficiency coefficient.

In model [2.2], agent i pays for his/her education expenses during time t. This factor makes agent i choose to spend less time in on-the-job training because further education investment probably does not pay off much in salary. The t-1 period education cost is free to agent i (which is paid by agent i's parents, agent i-1), so agent i should take advantage of it while his/her parents are paying the tuition rather than pay for the second period education by him/herself. Even if the cost is free for agent i's second period education (i.e., π^i=0), agent i would choose less second period education because he can still accumulate knowledge from working. This explains why most people do not want to make extra effort to receive training or education while they work unless it will greatly increase their salary. Therefore I conclude from the second model that if firms wish to see workers willingly utilize more training and education, the firms will have to provide sufficient incentive to their workers. The incentive would include these basic elements: inexpensive education costs, promised salary increases, and the time workers spend in education and training counting as working hours.

[model 2.3]

Model [2.3] is another extension of model [2.1]. I made the same assumptions as in model [2.1]. In addition I also assume that family education and socialization can serve as a knowledge transfer medium. The adult and elder generations can 'give' part of their knowledge capital to their offspring by family education, advising and socialization between families.

The budget constraint for agent i at time t is the same as model [2.1]:

$$R_{t+1}\left[W_t(1+\hat{q}_t^i)H_t^i - C_t^i - \pi^{i+1}edu_t^{i+1}\right] \geq C_{t+1}^i$$

However, the time constraint now is revised to incorporate family education and socialization.

(46) $1 \geq edu_{t-1}^i + Take_{t-1}^i$

(47) $1 \geq H_t^i + Take_t^i + Give_t^i$

(48) $1 \geq L_{t+1}^i + Give_{t+1}^i$

So, basically 'time' is an opportunity cost to agent if s/he wants to 'give' or 'take' knowledge capital within families. This makes the 'time' factor becomes a resource to trade for knowledge. Therefore it follows that, agent i at time t-1 (child stage) is a time taker. S/he spends time with his parents and acquires some knowledge transferred from them (agent i-1): so the time is being given by agent i-1 and being used by agent i. S/he is a pure time taker ($Take_{t-1}^i$) at time t-1 because s/he does not give his/her time to others. Agent i at time t spends time with his/her children (agent i+1) and transfer part of his knowledge to his children. S/he also spends time with his parents (agent i-1) and acquires some knowledge. So agent i is both a time taker and giver at time t ($Take_t^i, Give_t^i$). Agent i at time t+1 (retired stage) is a pure time giver. S/he spends time with his children (agent i+1) and transfers part of his/her knowledge to agent i+1. Similarly agent i-1 could directly transfer knowledge to agent i+1 by spending time with his/her grandchild. What is required to incorporate this concept is to revise the time constraints to incorporate direct transfer between agent i+1 and agent i-1. At this point, I try not to incorporate the knowledge transfer between grandchild and grandparent generations in order to keep the model simple.

Now I combine the time constraints to obtain a life cycle time constraint for agent i.

$$(49) \qquad 1 \geq edu_{t-1}^i + [Take_{t-1}^i + Take_t^i] + [Give_t^i + Give_{t+1}^i] + H_t^i + L_{t+1}^i$$

or

$$(50) \qquad 1 \geq [edu_{t-1}^i + Take_{t-1}^i] + [H_t^i + Take_t^i + Give_t^i] + [L_{t+1}^i + Give_{t+1}^i]$$

I re-ordered the life cycle time constraint in ascending order with respect to time period in equation (50) so the reader can see it more clearly. Now I clarify the $Take_t^i$ and $Give_t^i$ terms. The $Take_t^i$ term in first bracket only affects the edu_{t-1}^i in the same bracket, it does not affect other terms in the second and the third brackets. Similarly the $Take_t^i$ and $Give_t^i$ in the second bracket only affect H_t^i and L_t^i in the second bracket but not terms in first and third brackets. The reason is that if agent i decides to spend more time with parents in t-1 period (the first bracket), it only reduces his/her time spent in school education. The same applies to the Take and Give terms in other brackets. However, the edu_{t-1}^i, H_t^i and L_{t+1}^i could affect each other regardless of time periods. It is because the agent could choose to go to school longer, or to work longer, or to retire earlier. So agent i could choose to spend more time in period t-1 (the first bracket), or more time in period t (the second bracket), or more time in period t+1 (the third bracket). But no matter what is the agent's choice, his/her aggregate time in the lifetime is fixed (which is normalized to one in the life time constraint).

In order to simplify my calculation, I shrink $[Take^i_{t-1} + Take^i_t]$ to only $Take^i$,and $[Give^i_t + Give^i_{t+1}]$ to only $Give^i$. This reduces four variables to only two variables and time scripts in each are dropped. So what these variables mean is how much time agent i in aggregate spends in taking knowledge from his/her parents and giving his/her knowledge to his children.

According to the above conditions the knowledge capital that agent i could have is:

$$(51) \qquad \hat{q}^i = [\Phi^i H^i_t + \Omega^i edu^i_{t-1}] + [\delta^i Take^i \hat{q}^{t-1}]$$

The first bracket in the above equation represents the knowledge acquired from accumulation and the second bracket represents knowledge acquired from the transfer from agent i-1 for agent i. Parameter δ^i represents how efficient agent i is in converting the knowledge s/he takes from the transfer to his/her own knowledge. I also assume that the parameters Φ^i, Ω^i and δ^i are constant over time. And for simplicity, I assume that the residuals of the knowledge transfer term go away after two generations and are embedded in agent i-1's knowledge accumulation term. So that agent i takes knowledge from agent i-1, and agent i-2's knowledge which is embedded in agent i-1's knowledge. Hence, agent i-2's knowledge is not necessary to show up in the calculation for agent i's knowledge capital. So that:

$$(52) \qquad \hat{q}^{i-1} = [\Phi^{i-1} H^{i-1}_{t-1} + \Omega^{i-1} edu^{i-1}_{t-2}] + [\delta^{i-1} Take^{i-1} \hat{q}^{t-2}]$$

$$=[\Phi^{i-1}H_{t-1}^{i-1}+\Omega^{i-1}edu_{t-2}^{i-1}]$$

Expanding the life cycle budget constraint:

$$(53)\qquad R_{t+1}[W_tH_t^i(1+(\Phi^iH_t^i+\Omega^i edu_{t-1}^i+\delta^i Take^i\hat{q}^{t-1})-C_t^i-\pi^{i+1}edu_t^{i+1}]\geq C_{t+1}^i$$

So the utility function of agent i can be represented as follows:

$$(54)\qquad U_t^i=U_t^i\left(C_t^i,C_{t+1}^i,edu_{t-1}^i,H_t^i,L_{t+1}^i,Take^i,Give^i,edu_t^{i+1}\right)$$

The utility maximization for agent i can be described as follows:

$$(55)\qquad MaxU^i=U^i+\beta^iU^{i+1*}$$

Subject to the life cycle budget constraint and life cycle time constraint:

$$(56)\, C_{t+1}^i-R_{t+1}[W_tH_t^i(1+(\Phi^iH_t^i+\Omega^i edu_{t-1}^i+\delta^i Take^i\hat{q}^{t-1})-C_t^i-\pi^{i+1}edu_t^{i+1}]\leq 0$$

$$(57)\qquad edu_{t-1}^i+H_t^i+L_{t+1}^i+Take^i+Give^i\leq 1$$

Where U^{i+1*} is the children's utility, and

$\beta^i>0$ if agent i loves children

$\beta^i<0$ if agent i dislikes children

Assuming the Inada condition holds, then according to the Kuhn-Tucker condition we can solve the utility maximization problem for agent i with the Lagrangian equation.

$$(58)\qquad V=[U^i+\beta^iU^{i+1}]-\lambda_1[C_{t+1}^i-R_{t+1}[W_tH_t^i(1+(\Phi^iH_t^i+\Omega^i edu_{t-1}^i+\delta^i Take^i\hat{q}^{t-1})$$

$$-C_t^i-\pi^{i+1}edu_t^{i+1}]]-\lambda_2[edu_{t-1}^i+H_t^i+L_{t+1}^i+Take^i+Give^i-1]$$

Furthermore, at equilibrium there are three conditions must be satisfied:

First,

$$(59)\qquad Take^i=Give^{i-1}.$$

The time agent i chooses to spend to acquire knowledge from agent i-1 should be equal to the time agent i-1's chooses to spend to give knowledge to agent i. Second,

(60) $Give^i = Take^{i+1}$.

Same as above, the time agent i chooses to spend should equal agent i+1's choice as well. Third,

(61) $\left[edu^{i+1}\right]^{i+1} = \left[edu^{i+1}\right]^{i}$ and $\left[edu^{i}\right]^{i} = \left[edu^{i}\right]^{i-1}$.

At this point I make an implicit assumption that there is no government at work. So agent i+1's education expense depends totally on agent i's support. And similarly agent i's education expense depends on agent i-1's support. Thus, agent i+1's choice of education level (left hand term of first equation) should equal i's choice of education level s/he could afford for agent i+1. And the same applies to agent i's choice of education level (the second equation).

According to the above conditions, agent i's utility maximization problem can be solved. The first order conditions are similar to the previous models. In addition there are two first order conditions regarding $Take^i$ and $Give^i$ choice variables that should be taken into account:

(62) $\dfrac{dV}{dTake^i} = U^{i\ \prime}_{take^i} + \lambda_1(R_{t+1}W_t H^i_t \delta^i \hat{q}^{i-1}) - \lambda_2 = 0$, and

(63) $\dfrac{dV}{dGive^i} = U^{i\ \prime}_{Give^i} + \beta^i(R_{t+2}W_{t+1}H^{i+1}_{t+1}\delta^{i+1}\hat{q}^i)U^{i+1\ \prime}_{Take^{i+1}} - \lambda_2 = 0$.

From the above first order conditions I derive some useful comparative statics.

$\frac{dTake^i}{dW_t} < 0$ If average wage rate increases, agent i is more likely to spend less time consulting with his/her parents because agent i does not need more knowledge to become wealthier.

$\frac{dGive^i}{dW_t} < 0$ If $\beta^i > 0$, which is a normal condition, agent i is more likely to spend more time with children if the average wage rate decreases because s/he would rather allocate the time to teach his/her own children that can have a higher expectation of return in the future rather than work more now and get little more salary.

$\frac{dGive^i}{d\pi^{i+1}} > 0$ If $\beta^i > 0$, agent i is more likely to spend more time teaching and consulting his/her children if children's education costs increase.

$\frac{dH_t^i}{d\hat{q}^{i-1}} < 0$ If agent i's parents are more knowledgeable and resourceful, agent i is more likely to work less because agent i has higher knowledge capital that was transferred from his/her parents, substituting for personal effort.

In this chapter, I established mathematical models based on economic principles for the analysis of the knowledge capital accumulation and transfer. These models are intuitive; nonetheless, they suggested many important results that explained socio-economic phenomena. To a certain extent, these models explained the behavior of an individual when s/he is faced with the decision to invest in his/her own knowledge capital and the children's education. In these models, the effect of population growth, bequest from generation to generation, government intervention and knowledge capital depreciation are removed for simplicity. These models could be further extended to incorporate these factors.

I need to test the results of my theoretical model. Due to the difficulties in gathering micro-level data, I decide to use macro-level data for my analysis because it is readily accessible and some macro-level factors can be treated as proxies to the variables in my model. As suggested by my model, education and experience comprise knowledge capital, and the more knowledge capital an agent has, the higher the productivity s/he should have. In the macro-level empirical analysis, the economy's knowledge capital consists of the education of its citizenry and the accumulation of research and development work in both public and private sectors. If an economy has more knowledge capital, the benefit should reflect in its national productivity, ergo, higher GDP per capita. Therefore I will examine the relationship between economic performance, higher education and research and development (R&D) expenditure in U.S. data in the next chapter.

Chapter 3

In recent years there has been a demographic change in American higher education. The change in higher education structure was caused by a socio-economic change (Burelli, 2003; Hill, 2002; NSF, 1996). As Drucker and other scholars have pointed out, knowledge is and will be the driving force of the economy. Based on Nonaka's knowledge creation theory, one of the fundamental sources of knowledge that fueled our economic development is formal education. The linkage between education, the accumulation and application of knowledge capital and socio-economic development should therefore be strengthened. As our society advances into a knowledge-based economy, the impact of structural change on our society's higher education should not be overlooked. In this chapter, I have focused my research on science and engineering (S&E) fields in particular because these fields have been treated as important sources of knowledge input for high- tech industries. Such high tech-industries in the United States are usually treated as a benchmark in the social development among OECD member countries. In my research I found that there is a general decline in growth rate of American university level S&E degrees awarded over recent decades. Furthermore, I discovered an increase in the ethnic and gender diversities of the S&E fields. Lastly, my research revealed that the rate of enrollment and degrees awarded in both undergraduate and graduate levels in science and engineering display a 10-year cyclical pattern.

According to Burelli (2003) and the data from the Division of Science Resource Statistics of National Science Foundation, there were about 429,500 students enrolled in S&E at the graduate level in 2001, which was a four percent increase from 2000, but it was lower than the 435,700 students who were enrolled in 1993. As a matter of fact, the number of United States citizens and permanent residents enrolled in S&E increased only one percent from 2000 to 2001, and that was the first increase since 1994. Between 1993 and 2001 the number of graduate student in S&E dropped 20%. This significant change should concern American educators. In addition, in the 1990s the greatest gain occurred in computer science, which showed a 10% increase. Although the student enrollment rate in computer science still keeps growing, it is no longer the most popular field. Starting from 2000, Biochemistry Engineering has become the most popular choice in S&E; it grew 11% between 2000 and 2001. In the second place was material engineering, with an 8% increase, and in third place electric engineering with a 7% increase. In spite of the slight recovery of student enrollment rate in S&E fields, the percentage of students who pursue undergraduate and graduate level education in S&E is still lower than previous decades. The number of doctorates awarded in Physics between 1993 and 2000 dropped 22%, while its drop between 1996 and 2000 was 15%. From Figure 3.1, we can clearly see that the post-WWII era has the greatest gain in Doctorate, Master's and Bachelor degrees. The trend for university level degrees awarded was low in the post Vietnam War era; the 'university-level-degree-award-rate' increase was below one percent between years. The third wave of increase was between 1986 and 1995. According my observation in Figure 3.1, there appear to be a 10-years cyclical pattern in students pursuing higher education. The year 2000 should be the peak of its cycle, however, the peak in 2000 was lower than all previous peaks, except the one in the 1980's during the post Vietnam War era. From Figure 3.3, we can see S&E also displayed the same pattern. There is a general decline in the enrollment and degree awarded in S&E fields.

Another change in S&E is that the students are more diverse than before and will be even more so in future. This diversification is mainly due to the change in population demographics of the United States. According to the data from U.S. Census Bureau, the population of U.S. minorities including Asians, Blacks, Hispanics and Native Americans, is expected to be close to fifty percent of the total U.S. population before 2050. Asians and Hispanics account for the largest population growth because of immigration, while there is little increase in the Black and Native American population. At the graduate level of S&E, Black and Hispanic enrollment increased 4%, Native American enrollment increased 5%, and Asian and Pacific Islander enrollment increased 5% between 1990 and 2000. The undergraduate degrees awarded to underrepresented minorities in S&E grew substantially in the 1990's. Between 1990 and 1994 there was a 44% increase in undergraduate degree awarded to Blacks, a 47% increase in undergraduate degree awarded Hispanics and a 58% increase in undergraduate degree awarded to Native Americans. Part of the reason for the increase in degree awarded to minorities was due to Affirmative Action and Equal Opportunity Act. Despite the increases, minorities comprised 28% of entire student population but only 12% in science and engineering.

The gender difference in higher education has always been a major concern for American educators. Although the ratio of female participation in S&E has been increasing steadily in the past thirty years (see Figure 3.5), the number of women in S&E is still lower than in other fields. Women scientists and students in S&E did not receive the same respect as men did in the U.S. (Benteley, 2003). Compared to some advanced European countries such as France, Germany, the Netherlands, Finland and Italy, the U.S. has awarded the lowest share of doctorate degrees to women in the natural sciences. In Italy 68% of doctorate degree is awarded to women. More over, in Spain women receive 44% of doctoral degrees in the natural sciences, and in France 41%. In the United States, women receive only 32% of doctoral degree in the natural sciences (Benteley, 2003; NSF 2002). On average, women are more prevalent and competitive in psychology, social sciences and biological sciences. Studies by the National Science Foundation (2002,2003) indicate that although women accelerate faster than men in receiving education, in S&E, women earn lower salaries, and are promoted less frequently, and are less likely to earn tenure and full professorship in academic careers. Some argue that women are promoted less because women are less productive academically -- on average women publish 20% less than men (Benteley, 2003; NSF 2002). However, I think the lack of publishing productivity is not the major reason why women are promoted less frequently. Benteley (2003) shows that female economists actually publish more than male economists. In my own experience in the economic schools, I have yet to encounter a female economic professor who earned a full professorship. It is possible that women are promoted less often because they have less support and fewer social opportunities among senior male professors who have voting rights during the promotions of junior professors. In addition, women have more family responsibilities during child-bearing. Benteley points out that women receive fewer promotions when they are young, but that they are no different for older men and women. It is interesting that, for both men and women, the decision to grant them tenure in their academic careers is usually made between the ages of 28 and 38. Women at this age are more likely to have children, which would put them at a disadvantage in getting tenure and promotion.

The contribution to the American society by people with different ethnic background has been always important. Beside the underrepresented minorities in the United States international students and scholars play important roles economically, academically and socially. Many international students choose to work in the United States while some choose to return to their home countries after graduation. Those who choose to work in their home countries usually become important sources of knowledge and comprise the elite work force. They usually receive high societal respect because they are foreign scholars. In 2001 the number of international students in the U.S. with temporary visas (F-1, J-1) increased 9% to 133,300 from 121,800 in 2000 (Hill, 2002; NSF, 2000). Between 1994 and 2001 the total international student enrollment in American universities increased 133%. In S&E, international students account for 34% for total student population. Asian students comprised the majority of the U.S. foreign doctorate recipients. Among fields in S&E, computer science has the largest increase (16%) and engineering has the second largest increase (11%). Although these increases look successful, one point that should concern American educators is that fewer international students pursue doctorate degrees in S&E than before. According to Hill (2002), non-U.S. citizens or international students comprise over half of the 22% decline in doctorate degrees awarded in Physics. To be specific, the number of non-U.S. citizens or international students who earn doctorate degree dropped 28% in Physics and 20% in engineering from 1996 to 2000. These numbers might not be representative of all fields in S&E, but the general trend of decreases in international doctorate students is clear. There are three reasons I can offer to explain this trend. First, there was a regional economic disturbance in Asia between 1994 and 2000. The financial crisis swept through Korea, Japan, Taiwan and China, and shrunk most people's income. Hence, students who rely heavily on family financial support for studying in U.S. universities could not continue to pursue expensive and time-consuming doctorate degrees. Secondly, American universities lowered the amount of financial support for doctoral students who came from countries with a better economic performance record such as Japan, Taiwan and Korea. As a matter of fact students from China, Korea and Taiwan make up almost two-thirds of the decline in doctorates awarded to non-U.S. citizens. Lastly, the job market for graduates in S&E shrunk due to a global economic recession and collapse of the dot com phenomenon. The crash of the American stock market left many high tech companies unable to afford expensive workers with doctoral level education. In addition, the budget cuts by the U.S. federal government prevented public universities from hiring new professors.

The declining trend for students pursuing higher education in S&E could pose a serious problem to U.S. industries and the U.S. economy. Furthermore, it may affect countries or economies that have a higher dependency on the U.S. economy such as the Pacific-rim countries. To promote greater domestic and international social economic welfare development, sponsorship and financial support to doctoral students, domestic or foreign, in the S&E should be encouraged. The ten year cyclical pattern of college enrollment observed in the past few decades may be useful in predicting future trends in U.S. higher education.

The Schumpeterian growth literature (1939, 1934) has given many scholars direction for research in technological innovation, diffusion, and economic growth. Following the Schumpeterian literature, Phelps and Nelson (1966) wrote on education, technological change and economic growth. Phelps and Nelson argued that the process of education could be viewed as a form of investment in people as educated people are the bearers of human capital. The rate of return on education should become greater where higher technological achievements are present in the economy. In a way, the society would build more on human capital relative to tangible capital. Faster technological progress and diffusion could benefit from highly educated people. The benefit of human capital investment would gradually show up in terms of economic growth. Therefore, the implication of correcting the misspecification in the production function by inserting an index of education attainment to characterize the relationship between education and dynamics of production should not be overlooked (Nelson and Phelps, 1966).

Empirical Results

Due to the difficulties in gathering micro-level data, I decide to use macro-level data for my analysis because it is readily accessible and some macro-level factors can be treated as proxies to the variables in my model. As suggested by my model, education and experience comprise knowledge capital, and the more knowledge capital an agent has, the higher the productivity s/he should have. In the macro-level empirical analysis, the economy's knowledge capital consists of the education of its citizenry and the accumulation of research and development work in both public and private sectors. If an economy has more knowledge capital, the benefit should reflect in its national productivity, ergo, higher GDP per capita. Therefore I will examine the relationship between economic performance, higher education and research and development (R&D) expenditure in U.S. data. I test the relationship between GDP growth and the growth of the university-level education attainment rate and research and development expenditures. I used the data collected from NIPA, the Economic Report to the President, NSF surveys for R&D spending and IPEDS database from the National Center of Education Statistics to construct my dataset. The dataset includes the following economic variables for the analysis: GDP and growth from the year 1946 to 2000, average labor hours per week, average labor wages per week, population and population growth rate, income per capita and real consumption per capita from the year 1959 to 2000.

The education data includes the detailed statistics of total undergraduate and graduate degrees earned from 1966 to 2000. The datasets further break into smaller categories by gender, types of degree earned and the major subject degree. The observations for the year 1999 are missing through the whole education dataset except in Ph.D. degrees. This occurred as Congress did not pass the release of use for the data in that particular year. As mentioned before, despite population growth, there was a constant decrease in the growth rate of university level degree awards since 1990. The decrease is the most significant in engineering, the physical sciences and other heavily mathematically-oriented fields.

The R&D data are assembled from four NSF surveys: the Survey of Industrial R&D spending, the Survey of Universities and Colleges R&D expenditure, the Survey of Federal Funded R&D spending and the Survey of R&D Funded by Non Profit Organizations. These datasets consist of data from 1953 to 2002. One section of the data also contains the R&D spending from six other industrialized countries from 1981 to 2001. The dataset is further categorized into defense or non-defense R&D spending, as well as type and patterns of the R&D spending: basic research and applied research. The data shows the R&D level of the U.S. averages 2.5% of the GDP since 1960. However, the federally funded R&D has been constantly decreasing from a high of 1.9% of GDP in 1964 to a low of 0.7% of GDP in 2000. By contrast, the non-federal funded R&D has been steadily increasing from 0.63% of GDP in 1953 to 2.02% of GDP in 2002. The 10-year averages of total R&D expenditure to GDP are 2.73% in 1960's, 2.22% in the 1970's, 2.59% in the 1980's and 2.57% in the 1990's.

My regression models are simple. I the real GDP (based on 1996) growth is calculated as $(GDP_t - GDP_{t-1}) / GDP_{t-1}$, and I use the same method to calculate the growth rate in university level degree awarded and Federal and Non-Federal R&D spending growth rate. I use the growth rate in my variables because it should correct the serial correlation problems between university level degree awarded, R&D spending and GDP. I also use Newey-West covariance estimator to correct for potential heteroskedasticity and autocorrelation problems in the regression. In the first model, I regress the GDP growth rate upon all higher education degrees attained and R&D investment between the year 1966 and 2000. In the second model, I regress the GDP growth rate upon the degrees attained in non-science and engineering. In the third model, I regress the GDP growth rate upon the degrees attained in science and engineering. The rationale behind my analysis is to see the effect of science and non-science degree attainment related to economic growth.

Key Variables

The symbols I use in this section of analysis and the variables they represent are listed below:

t	Calendar time in year
GDPGROWTH	The GDP data range from 1946 to 2000. It is indexed as 100 based on 1996 U.S. dollars. GDPGROWTH is calculated as $(GDP_t - GDP_{t-1}) / GDP_{t-1}$
BAGROWTH	The growth rate of Bachelor degrees received each year from 1966 to 2000 -- includes all fields.
MASTERGROWTH	The growth rate of Master degrees received each year from 1966 to 2000 -- includes all fields.
PHDGROWTH	The growth rate of Ph.D. degrees received each year from 1966 to 2000 -- includes all fields.

NONSCIBAGR	The growth rate of non-science Bachelor degrees received each year from 1966 to 2000.
NONSCIMAGR	The growth rate of non-science Master degrees received each year from 1966 to 2000.
NONSCIPHDGR	The growth rate of non-science Ph.D. degrees received each year from 1966 to 2000.
BSSCIGROWTH	The growth rate of Bachelor degrees received each year from 1966 to 2000 -- includes only science and engineering fields.
MSSCIGROWTH	The growth rate of Master degrees received each year from 1966 to 2000 -- includes only the science and engineering fields.
PHDSCIGROWTH	The growth rate of doctoral degrees received each year from 1966 to 2000 -- includes only the science and engineering fields.
FEDRDGROWTH	The growth rate of federally funded research and development spending, adjusted based on the 1996 U.S. dollar.
NONFEDRDGROWTH	The growth rate of non federally funded research and development spending, adjusted based on the 1996 U.S. dollar.

The Granger Causality Test

Granger Causality analysis is the most convenient way to look at causality effect between two variables. Granger (1969) proposed that in order to see whether variable X causes variable Y is to see how much of the current value of Y can be explained by past values of Y and then to see whether adding lagged values of X can improve the explanation. X is said to Granger Cause Y if knowing X helps in the prediction of Y, or that the coefficients on the lagged X's are statistically significant in explaining Y. In order to determine the best lag value of the variables to fit in my regression model, I examined the Granger Causality for the data in this section. The test statistics are reported as follows:

Null Hypothesis	OBS	F-Stat	Prob.
FEDRDGROWTH does not Granger Cause NONSCIBAGR, Lag 4	28	1.7988	0.1708
NONSCIBAGR does not Granger Cause FEDRDGROWTH, Lag 4	28	0.20575	0.9320
FEDRDGROWTH does not Granger Cause NONSCIMAGR, Lag 4	28	3.1880	0.0366**
NONSCIMAGR does not Granger Cause FEDRDGROWTH, Lag 4	28	0.8230	0.5266
FEDRDGROWTH does not Granger cause NONSCIPHDGR, Lag 7	27	7.23824	0.0016**
NONSCIPHDGR does not Granger cause FEDRDGROWTH, Lag 7	27	0.94272	0.5101

** 5% significance level
* 10% significance level

From the test statistics, the null hypotheses cannot be rejected for the FEDRDGROWTH and NONSCIBAGR. So it appears that the federal R&D spending growth and the increase in the Bachelor level non-science degree awards do not Granger Cause each other. However, I reject the null hypothesis that the federal R&D spending growth does not Granger Cause the increase in the Master's level non-science degree awards. The null hypothesis that federal R&D spending growth does not Granger Cause the increase in the Ph.D. level non-science degree awards is also rejected. However it seems that the increase in non-science Master's and Ph.D. level degree awarded do not Granger Cause the federal R&D spending growth.

Null Hypothesis	OBS	F-Stat	Prob.
NONFEDRDGROWTH does not Granger Cause NONSCIBAGR, Lag 5	27	0.2757	0.9198
NONSCIBAGR does not Granger Cause NONFEDRDGROWTH, Lag 5	27	2.6044	0.0660*
NONFEDRDGROWTH does not Granger Cause NONSCIMAGR, Lag 4	26	1.5767	0.2212
NONSCIMAGR does not Granger Cause NONFEDRDGROWTH, Lag 4	26	2.6626	0.0644*
NONFEDRDGROWTH does not Granger Cause NONSCIPHDGR, Lag 7	27	0.7165	0.6609
NONSCIPHDGR does not Granger Cause NONFEDRDGROWTH, Lag 7	27	2.28822	0.0934*

** 5% significance level
* 10% significance level

According to the above statistics, the null hypotheses for the increase of non-science Bachelor, Master's and Ph.D. level degree awarded do not Granger Cause the non-federal R&D spending growth can be all rejected at 10% significance level. However the hypotheses for the non-federal R&D spending growth does not Granger Cause non-science degree awards increase cannot be rejected. So it appears that to a certain degree, the increase in non-science degree awards will affect the business sector R&D spending growth in the longer term.

Null Hypothesis	OBS	F-Stat	Prob.
FEDRDGROWTH does not Granger Cause BSSCIGROWTH, Lag 4	28	1.7176	0.1877
BSSCIGROWTH does not Granger Cause FEDRDGROWTH, Lag 4	28	5.0496	0.0061**
FEDRDGROWTH does not Granger Cause MSSCIGROWTH, Lag 4	28	1.7756	0.1755
MSSCIGROWTH does not Granger Cause FEDRDGROWTH, Lag 4	28	0.6834	0.6120
FEDRDGROWTH does not Granger Cause PHDSCIGROWTH, Lag 3	31	2.6317	0.0731*
PHDSCIGROWTH does not Granger Cause FEDRDGROWTH, Lag 3	31	1.6290	0.2090

** 5% significance level
* 10% significance level

According to the above statistics, I reject the null hypothesis that the increase in Bachelor level science and engineering degree awards does not Granger Cause federal R&D spending growth at 5% significance level. The causality effect does not show in science Master's level S&E degree growth and federal R&D spending growth. However, I reject the hypothesis that federal R&D spending growth does not Granger Cause the increase in Ph.D. level science and engineering degree awards. So, it looks like the federal R&D spending growth should have some effect in increasing the science and engineering doctorates in near term (3 lags).

Null Hypothesis	OBS	F-Stat	Prob.
NONFEDRDGROWTH does not Granger Cause BSSCIGROWTH, Lag 4	28	0.5119	0.7277
BSSCIGROWTH does not Granger Cause NONFEDRDGROWTH, Lag 4	28	1.4400	0.2594
NONFEDRDGROWTH does not Granger Cause MSSCIGROWTH, Lag 4	28	4.21186	0.0131**
MSSCIGROWTH does not Granger Cause NONFEDRDGROWTH, Lag 4	28	0.5674	0.6893
NONFEDRDGROWTH does not Granger Cause PHDSCIGROWTH, Lag 7	27	4.2079	0.0144**
PHDSCIGROWTH does not Granger Cause NONFEDRDGROWTH, Lag 7	27	1.1488	0.3968

** 5% significance level
* 10% significance level

Based on the above statistics, non-federal R&D spending growth and the bachelor level science and engineering degree awards have no causality effect. However it looks like non-federal R&D spending growth has some effect in increasing the Master's and Ph.D. level science and engineering degree awards.

The following tests examine the causality effect between GDP growth, federal and non-federal R&D spending.

Null Hypothesis	OBS	F-Stat	Prob.
GDPGROWTH does not Granger Cause FEDRDGROWTH, Lag 2	45	4.25864	0.0211**
FEDRDGROWTH does not Granger Cause GDPGROWTH, Lag 2	45	0.0442	0.9568
GDPGROWTH does not Granger Cause FEDRDGROWTH, Lag 5	42	5.1794	0.0014**
FEDRDGROWTH does not Granger Cause GDPGROWTH, Lag 5	42	2.20467	0.0790*

** 5% significance level
* 10% significance level

From the above test results, it seems that the Granger Causality runs one-way from GDP growth to federal R&D spending growth in the shorter term. However, the Granger Causality runs both ways between GDP growth and federal R&D spending growth in the longer term.

Null Hypothesis	OBS	F-Stat	Prob.
GDPGROWTH does not Granger Cause NONFEDRDGROWTH, Lag 2	46	6.7126	0.0031**
NONFEDRDGROWTH does not Granger Cause GDPGROWTH, Lag 2	46	2.0741	0.1390
GDPGROWTH does not Granger Cause NONFEDRDGROWTH, Lag 3	44	2.6068	0.0661*
NONFEDRDGROWTH does not Granger Cause GDPGROWTH, Lag 3	44	3.4709	0.0256**

** 5% significance level

* 10% significance level

Above test results also suggest that the Granger Causality runs one-way from GDP growth to non-federal R&D spending growth in shorter term, but the causality runs both ways in longer term.

Summing up the above results, federal R&D and Non-federal R&D spending growth should have positive effect on GDP growth in the longer term, however, the effect of federal R&D spending growth on GDP growth is less significant compared to non-fed R&D spending growth. On the other hand, GDP growth contributes to federal and non-federal R&D spending growth in the shorter term. In addition, the federal and non-federal R&D spending growth have some positive effects in rising the attainment in Master's and Ph.D. level in either non-science related or science and engineering degree in the longer term. Also, to a certain degree, the increase in non-science degree awards will affect the business sector R&D spending growth in the longer term. However, the degree attainment growth rate in S&E does not affect federal R&D spending growth.

The Regression Models

Based on above Granger Causality test, the effect of the federal R&D spending growth on GDP growth is not as significant as the effect from non federal R&D spending growth. Therefore, I decide to use only non federal R&D spending growth as a variable in my regression models. In order to remove multi-collinearity problems in my regressions, I combine total degree awards at master's and Ph.D. level to a total graduate level degree awards with respect to all fields, non-science and science fields. Then I calculate the growth rate of graduate degree awards as:

$$TOTGRADGROWTH = (TOTGRAD - TOTGRAD_{-1}) / TOTGRAD_{-1},$$

$$NONSCIGRADGROWTH = (NONSCIGRAD - NONSCIGRAD_{-1}) / NONSCIGRAD_{-1}$$

$$SCIGRADGROWTH = (SCIGRAD - SCIGRAD_{-1}) / SCIGRAD_{-1}$$

The best-fit models are specified as following:

$$GDPGROWTH_t = C + BAGROWTH_{t-1} + TOTGRADGROWTH_{t-2} + NONFEDRDGROWTH_{t-3} + u_t$$

$$GDPGROWTH_t = C + NONSCIBAGR_{t-1} + NONSCIGRADGROWTH_{t-2} + NONFEDRDGROWTH_{t-3} + u_t$$

$$GDPGROWTH_t = C + BSSCIGROWTH_{t-1} + SCIGRADGROWTH_{t-2} + NONFEDRDGROWTH_{t-3} + u_t$$

The Regression Results

Table 3.1

Regression Result Concerning Total University Level Education Attainment

Dependent Variable: GDPGROWTH

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.020918	0.008315	2.515717	0.0181**
BAGROWTH(-1)	-0.436967	0.116994	-3.734946	0.0009**
TOTGRADGROWTH(-2)	0.354435	0.161624	2.192967	0.0371**
NONFEDRDGROWTH(-3)	0.196434	0.066208	2.966937	0.0062**
R-squared	0.174732			
Adjusted R-squared	0.083036			
Durbin-Watson stat	1.730445			

Note: The regression is estimated using ordinary least square (OLS), with a Newey-West heteroskedasticity-consistent Standard Errors and Covariance.

* significant at 10% level

** significant at 5% level

Table 3.2

Regression Result Concerning Non-Science University Level Education Attainment

Dependent Variable: GDPGROWTH

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.024316	0.007862	3.092862	0.0046**
NONSCIBAGR(-1)	-0.346776	0.122964	-2.820149	0.0089**
NONSCIGRADGROWTH(-2)	0.244769	0.138678	1.765018	0.0889*
NONFEDRDGROWTH(-3)	0.154164	0.064049	2.406980	0.0232**
R-squared	0.127936			
Adjusted R-squared	0.031040			
Durbin-Watson stat	1.731265			

Note: The regression is estimated using ordinary least square (OLS), with a Newey-West heteroskedasticity-consistent Standard Errors and Covariance.

* significant at 10% level

** significant at 5% level

Table 3.3

Regression Result Concerning Science and Engineering University Level Education Attainment

Dependent Variable: GDPGROWTH

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.022611	0.007093	3.187675	0.0036**
BSSCIGROWTH(-1)	-0.393371	0.131715	-2.986526	0.0059**
SCIGRADGROWTH(-2)	0.413018	0.199163	2.073772	0.0478**
NONFEDRDGROWTH(-3)	0.146334	0.080523	1.817293	0.0803*
R-squared	0.156015			
Adjusted R-squared	0.062239			
Durbin-Watson stat	1.782649			

Note: The regression is estimated using ordinary least square (OLS), with a Newey-West heteroskedasticity-consistent Standard Errors and Covariance.

* significant at 10% level

** significant at 5% level

From Table 3.1, the result indicates that the growth of graduate level degree awards (at a 5% significance level) and growth of non-federal R&D spending (both at a 5% significance level) are positively correlated with the growth of GDP. On the other hand, the growth of undergraduate level degree awards (at a 5% significance level) is negatively correlated with GDP growth.

As Table 3.2 shows, the growth of non-science undergraduate degree awards is significantly negative correlated with the GDP growth (at a 5% significance level). The growth of non-science graduate level degree awards and non-federal R&D spending growth are significantly positively correlated with the GDP growth (at 10% and 5% significance level respectfully).

The result from Table 3.3 is very similar with the result in Table 3.1 and Table 3.2. The coefficient for S&E undergraduate degrees is negative and significant at the 5% level. The growth of graduate level degree awards in S&E is positively correlated with GDP growth at the 5% significance level. Non-federal R&D spending shows a positive correlation and is significant at the 5% level.

The data of degree attainment in science and engineering shows there was a sharp increase between 1966 to 1975, about 7~10% increase each year. This trend reversed and picked up a negative direction in the next ten years until 1985. The average growth in science and engineering degrees attained between 1975 and 1985 was near zero percent. However, starting in 1995 the growth rate started picking up again, averaging about

4~7% a year. It is quite obvious that there is an approximately ten year cycle in the University-level science and engineering degree attainment. Starting from 1995, the growth rate of science and engineering degrees awarded started to decline again. The negative trend could likely to last until 2005. According to this prediction, there will be a shortage of science Master and Ph.D. graduates between 2005 and 2010. Furthermore, economic growth should not show up significantly until 2006 or even 2007 based on the two period lag relationship between GDP growth rate and the science and engineering degree attainment rate.

The federal R&D spending in terms of constant 1996 U.S. dollars since 1963 has been growing, however, as a ratio to GDP, it climbed to its highest point of 1.92% in 1964 and has been decreasing ever since to 0.78% in 2002. By contrast the non-federal R&D spending has been growing consistently in terms of both the 1996 dollars and as a ratio to GDP. The non-federal R&D spending to GDP ratio was initially lower than the federal R&D spending to GDP ratio, but it surpassed the federal R&D to GDP ratio since 1979, and it recorded a high of 2.02% of GDP in 2002 (see Figure 3.6 & 3.7). It is important to point out that Federal R&D spending also has positive effect on raising GDP growth. Therefore, its importance should not be taken lightly.

My regression results could suggest that if carefully planned and administrated, the R&D investment will have positive results on GDP growth. Many economists have criticized that the U.S. businesses do not think in terms of long term prosperity, but instead consider only short term profit (Nelson, 1981; Heilbroner and Thurow, 1994). This could affect the long-term development of public and private funded R&D projects. I suspect that much funding to support R&D projects, especially in the private sector, is cut or reduced during an economic recession. According to Epple (1991) that approximately only 3.2% of knowledge stock will remain after one year if a project is stopped, therefore, discontinuing R&D projects may cause loss of accumulated knowledge capital that could reflect in future GDP growth slowdown.

Summing up the above results, one important implication is found. Relatively speaking, as the economy grows there will be fewer people getting undergraduate level degrees and more people getting graduate level degrees. This suggests that there is a higher demand for highly trained and educated knowledge workers in a highly developed economy. Consequently, the increasing supply of knowledge workers in the total work force shall push the economy away from a traditional industrial and labor-based economy to a knowledge-based economy.

Chapter 4

Though many economists and social scientists agree that knowledge is important and that the study of its influences upon the society and economy should be emphasized, only limited research has been done on impact of knowledge on the economy. From the literatures I have reviewed, I have not found a good model that characterizes the flow of knowledge capital. I believe formal mathematical modeling can be helpful in understanding the nature of knowledge capital accumulation and transfer at individual level, or to a greater extent, it can also capture the behavior of research and development investment at organizational level. Therefore, I decided to create a model that can provide better insight and establish a more solid theoretical background to academia and businesses for further research in the field of knowledge economics.

I created a three-period overlapping generation model to characterize knowledge capital accumulation and transfer at individual level. I further provided two extensions to the model. The first extension, model [2.2], was shaped to study the effect of an adult continuing his/her education or receives on-the-job-training after starting to work. The extension suggested that due to the higher cost of education and further education investment probably does not pay off much in his/her salary, an agent would choose to spend less time in further education and on-the-job trainings. Additionally, even if the cost of education is free for agent's further education, the agent would choose such education less because s/he can still accumulate knowledge from working. Therefore, as model [2.2] suggested, if firms wish to see workers willingly receiving more training and education, the firms will have to provide sufficient incentive for their workers. The incentive would include these basic elements: inexpensive education costs, promised salary increases, and the time workers spend in education and training counting as working hours.

The second extension, model [2.3], was formulated to study the dynamics and effects of knowledge transfer and accumulation within families. Model [2.3] suggested that the time an agent allocated to his/her families will differ if the agent's income changes. If an agent receives a higher income, s/he actually would spend less time consulting with his/her parents. If an agent receives a lower income s/he would increase the time spent with his/her own children because s/he would rather allocate the time to teach the children that can have a higher expectation of return in the future rather than work in the present and get little pay off from his/her salary. Also, if an agent's parents are more knowledgeable and resourceful, the agent is more likely to work less because the agent has higher knowledge capital that is transferred from his/her parents substituting for personal effort. For example, if a person's parents are knowledgeable and well connected in the business world, the person would receive help from his/her parents telling the person what to do, what not to do and who to lookup to. The person is more likely to be successful faster in the business world than others due to his/her parents 'knowledge capital.'

The models I created are intuitive; nevertheless, they suggested many important results that explained socio- economic phenomena. To a certain extent, these models explained the behavior of an individual when s/he is faced with the decision to invest in his/her own knowledge capital and the children's education. However, in these models, the effect of population growth, bequest from generation to generation, government intervention and knowledge capital depreciation are removed for simplicity. These models could be further extended to incorporate these factors. For example, if the government is incorporated to the model, the effect of government subsidies to education can be studied and the results can be helpful for the policy makers.

Moreover, if the entities, the agents, in these models are replaced with business organizations and the assumptions and constraints revised to fit, I believe these models could help explaining business organizational behavior. For example, business can understand why and to what extent it should encourage its employees to receive more education and trainings. In addition, these models would characterize the behavior and dynamics for intra and inter-organizational knowledge transfer and accumulation, and thus useful suggestions can be made to business's R&D investment decision-making.

I also attempted to test the results of my theoretical model with empirical data. Due to the difficulties in gathering micro-level data, I decided to use macro-level data for my analysis because it is readily accessible and some macro-level factor can be treated as proxies to the variables in my model. As suggested by my model, education and experience comprise knowledge capital, and the more knowledge capital an agent has, the higher the productivity s/he should have. In the macro-level empirical analysis, the economy's knowledge capital consists of the education of its citizenry and the accumulation of research and development work in both public and private sectors. If an economy has more knowledge capital, the benefit should reflect in its national productivity, ergo, higher GDP per capita. Therefore I examined the relationship between economic performance, higher education and research and development (R&D) expenditure in U.S. data. I found that there is a general decline in science and engineering degree awards over recent decades in the United States, and the enrollment rate in the S&E displays a ten year cyclical pattern. This pattern can predict future trends in U.S. higher education and corresponding change in the economic structure. The R&D spending has a significant positive correlation with GDP growth. The statistical data further indicates that when the economy grows, more people will pursue graduate level degrees. More Master's and Ph.D. level graduates and R&D investment in the economy would help GDP growth. This reflects a higher demand for well-trained and highly-educated 'knowledge workers' in a highly developed economy. Consequently, the increasing supply of 'knowledge workers' in the total labor force pushes the economy away from a traditional industrial and labor-based economy to a knowledge-based economy.

As a matter of fact, I believe future research can be proposed to find more empirical evidences for my model by using more comprehensive firm-level data. To analyze the role that knowledge capital plays in a firm, these data will be useful: the firm's years in the industry, education level of its employees, firm's current R&D level relative to other firms in the industry, firm's R&D cost, overhead and production cost, firm's savings, re-investments, earnings and total outputs. If more data can be gathered from different firms in the same industry, the horizontal and vertical knowledge transfer among firms can be better characterized and analyzed.

Figure 3.1. University Degree Attainment Change Pattern

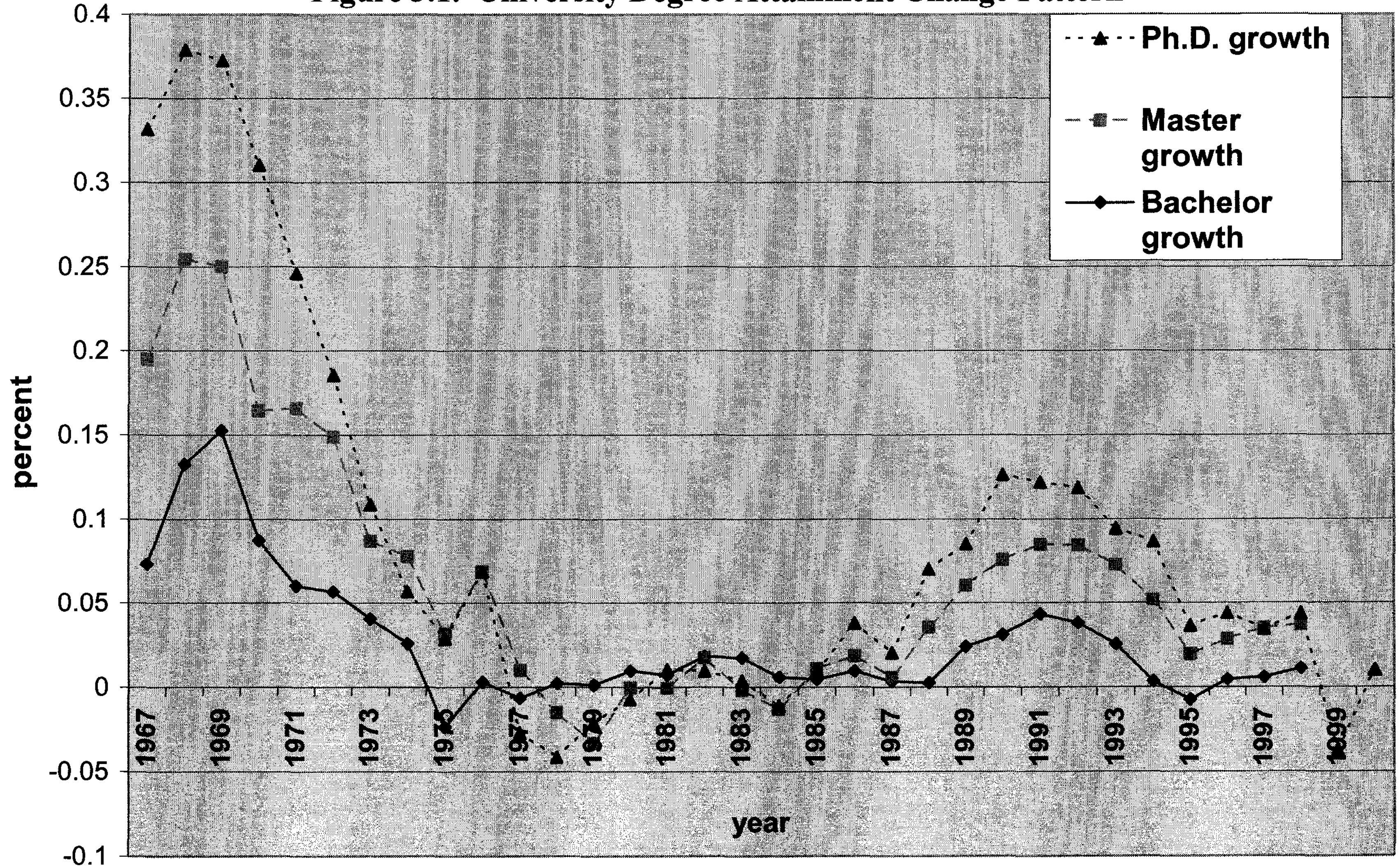


Figure 3.2 Population Growth Rate

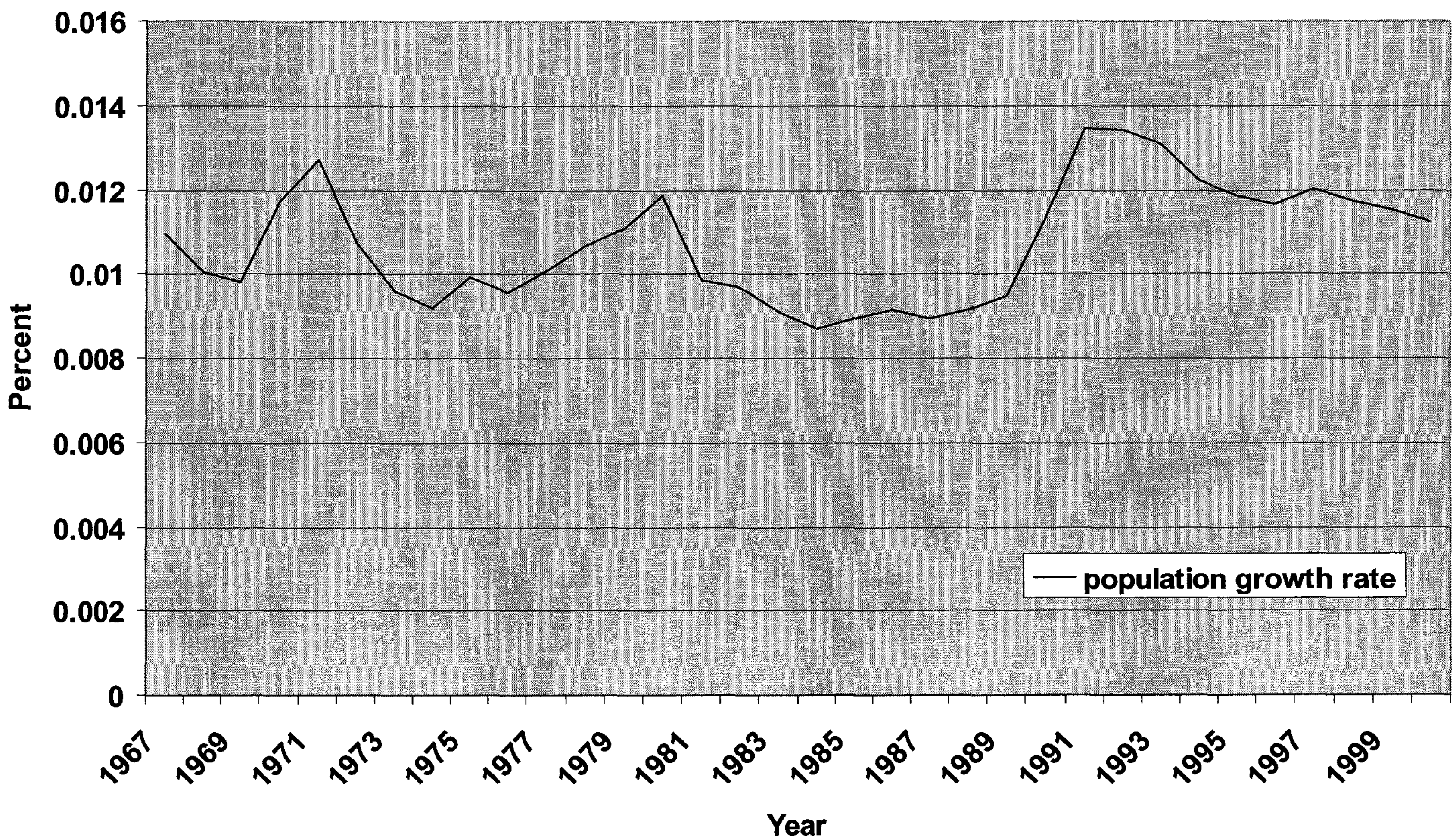
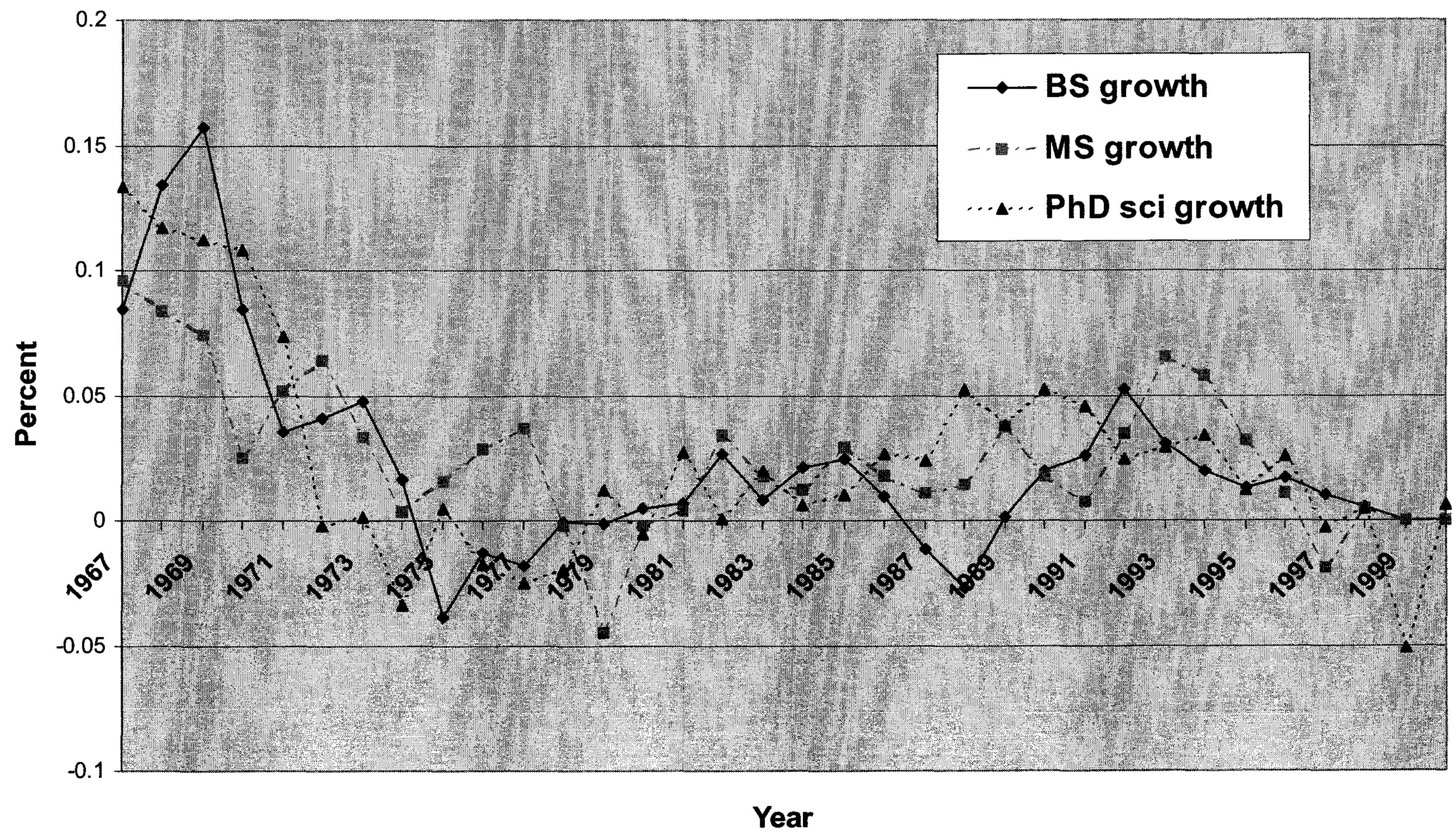


Figure 3.3 Science Degree Attainment



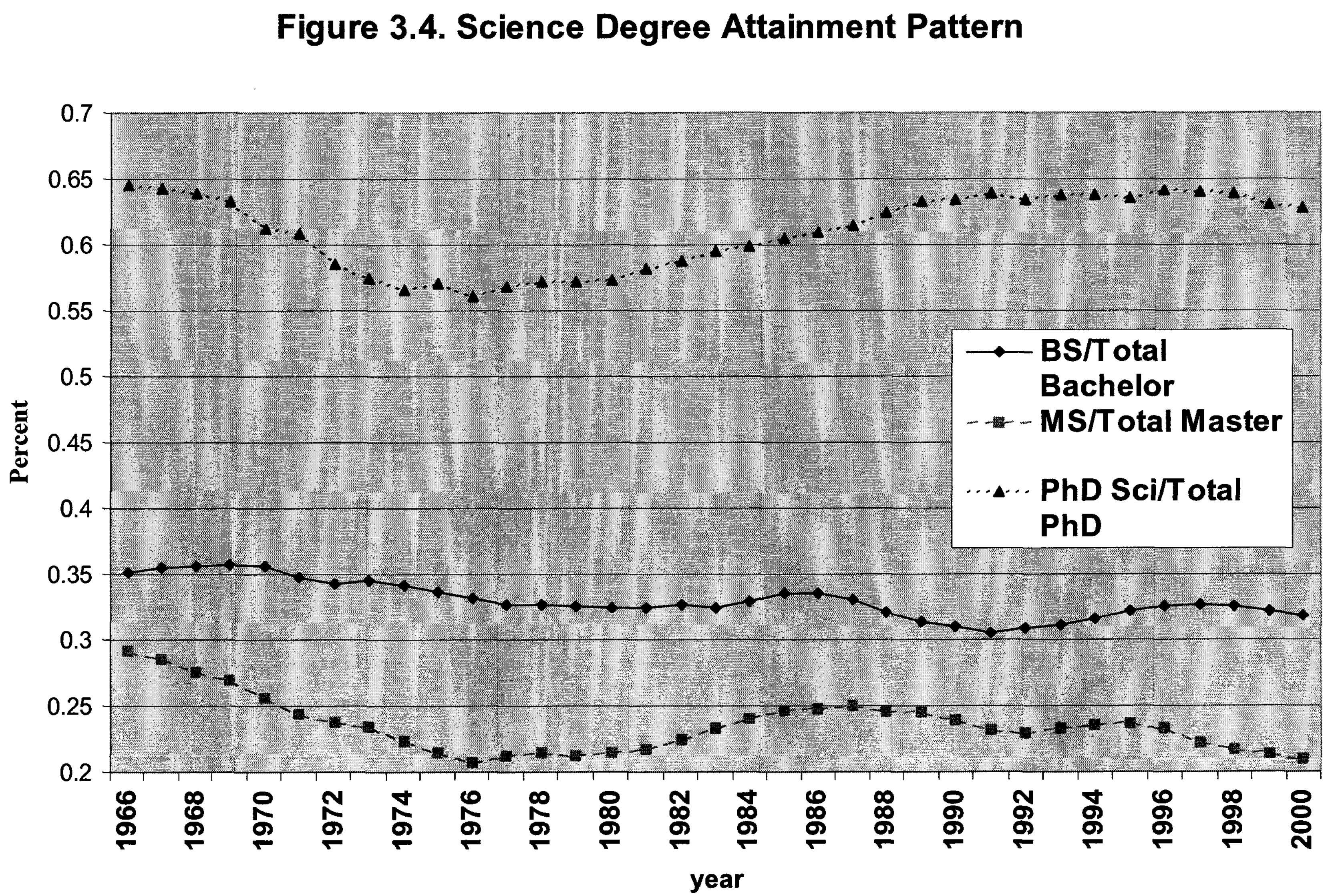


Figure 3.4. Science Degree Attainment Pattern
Percent
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
BS/Total Bachelor
MS/Total Master
PhD Sci/Total PhD
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
year

Figure 3.5. Female/Male ratio in S&E degree awarded

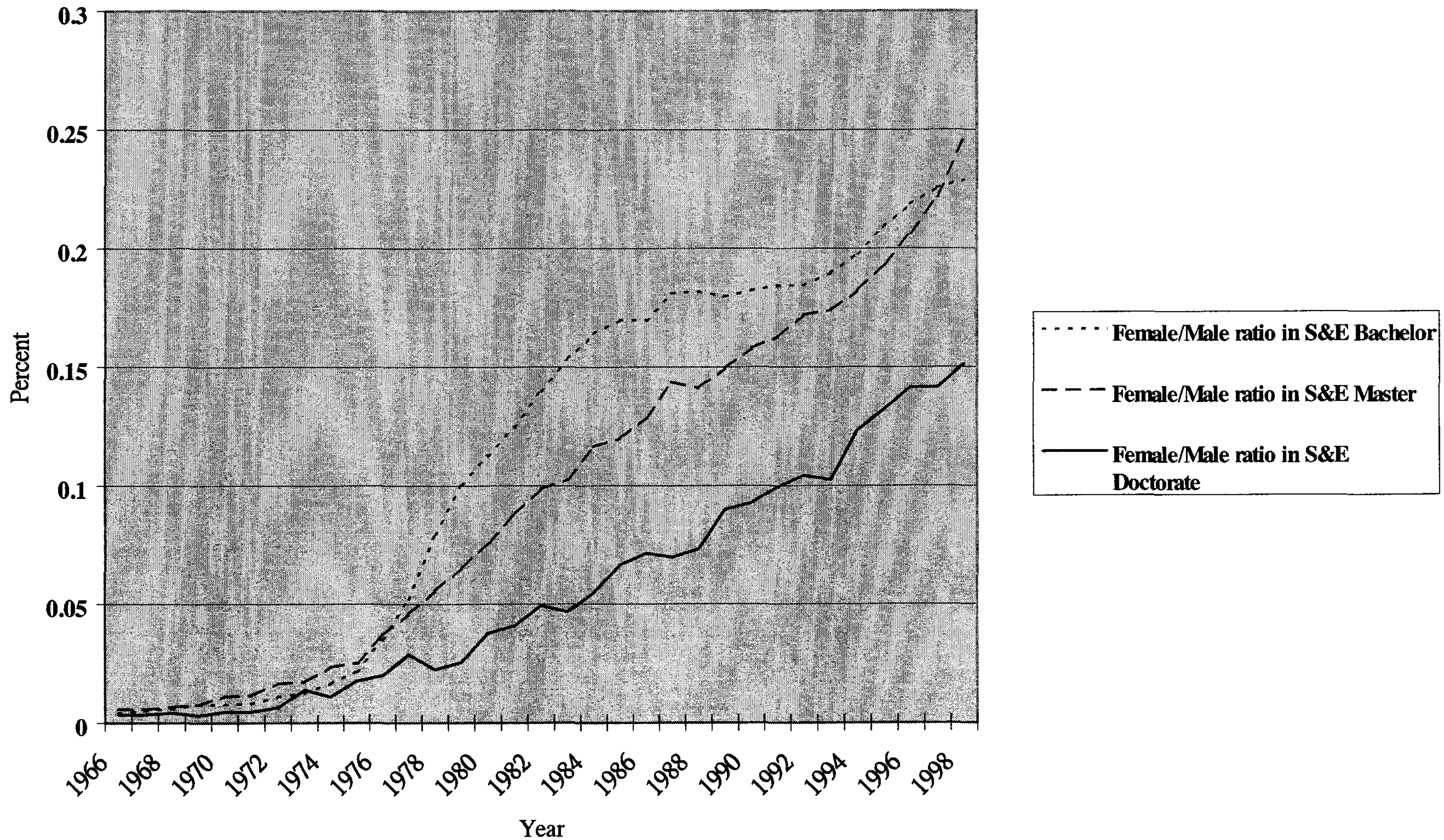


Figure 3.6. R&D Spending as Ratio to GDP Pattern

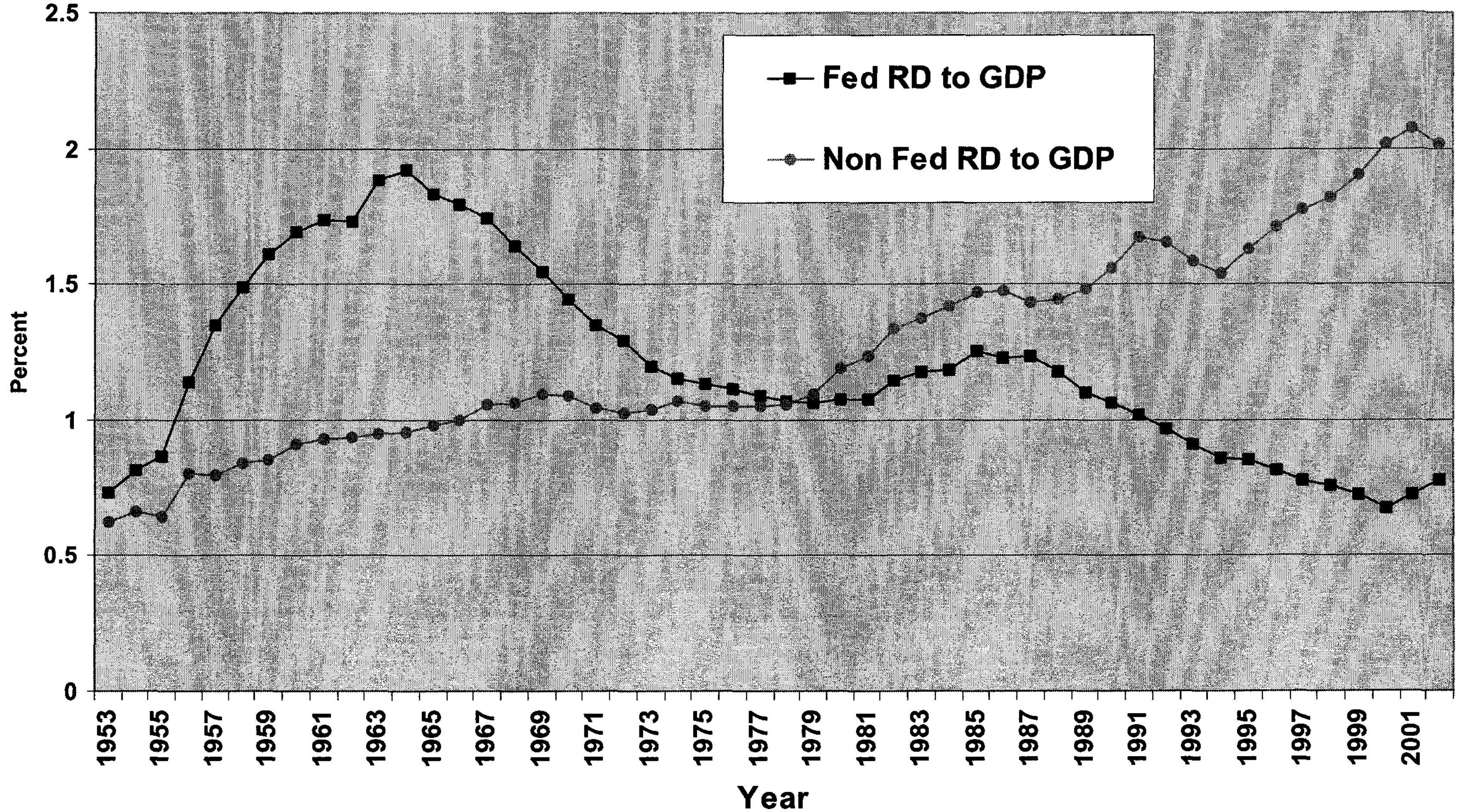
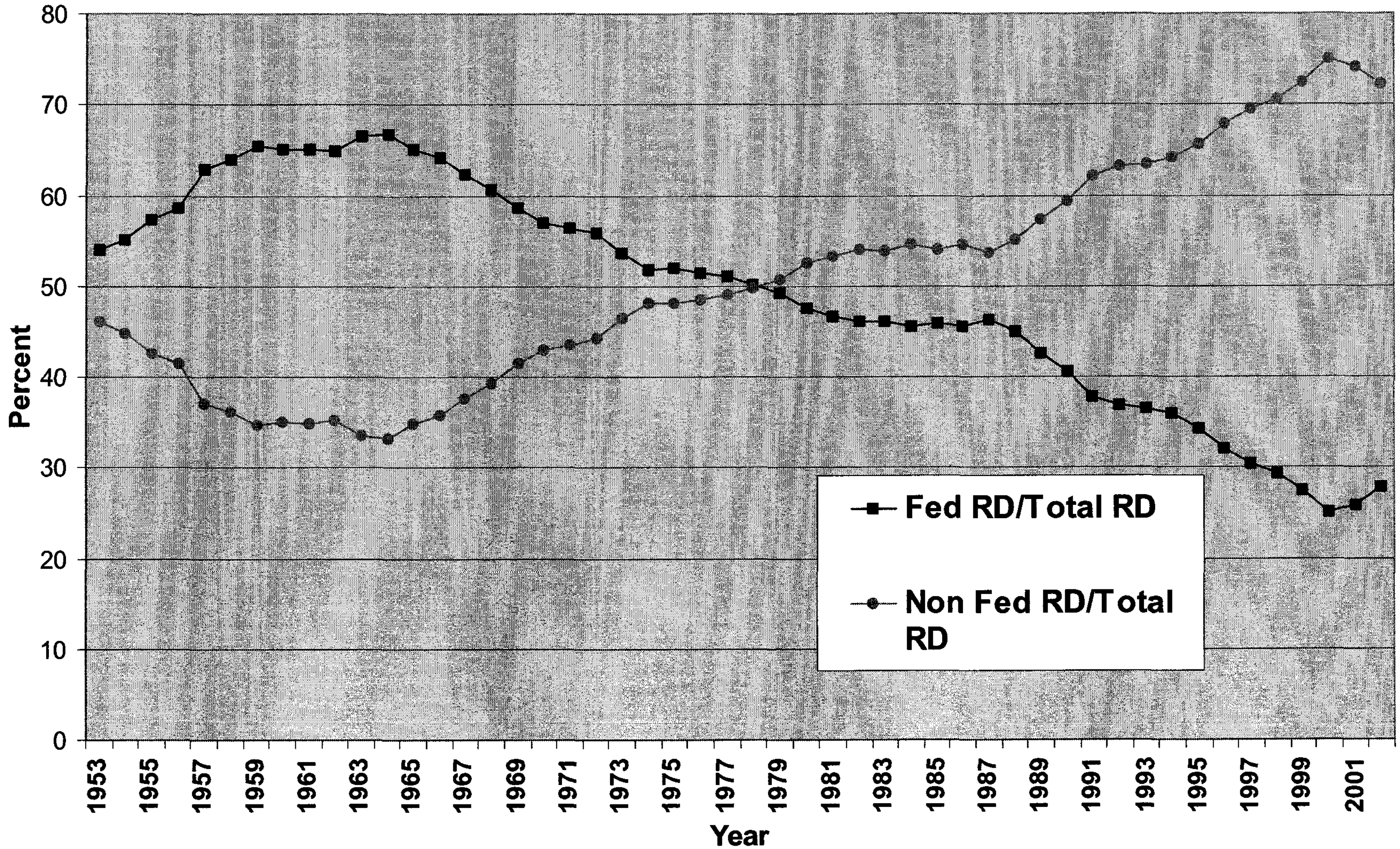


Figure 3.7. Fed/Non-Fed R&D Spending as Ratio to Total R&D Spending Pattern



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