Effectiveness of R&D Consortium for Industrial Growth in the Globalizing Economy – A Case Study of Semiconductor Industry –

by

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ABSTRACT

R&D Consortium is occupying the interest of policy makers as a means for industrial growth. One of the typical example is the semiconductor industry, in which many countries have formed consortia in the late 1980’s. Out of these nations, the United States and Korea industries have (re)gained competitiveness in terms of world market share. However, in order to understand the role of consortia in these competitiveness changes, the mechanism of technological development for industry’s growth should be recognized.

By assuming that technological development lies in its industrial structure and technological linkages, which connect firms both vertically and horizontally and both through non-proprietary and proprietary technology exchanges, this thesis analyses the relationship between the changes of competitiveness and those of technological linkages, and shows that, in order to be effective, consortia should be organized so that the technological linkages that they create will enhance the growth pattern of industry, which may be based on its industrial structure. Based on this fact, this paper recommends some possible amendments for a Japanese new semiconductor consortium.

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Part I. Introduction

Recently, technology policy is getting more and more attention from policy makers in the world as a means to promote economic growth. For example, in the United States, the Clinton administration issued in 1993 its idea for comprehensive technology policy to enhance industrial performance of the US in the world market, while in Japan, the government published its first Basic Plan for Science and Technology in 1996, following the Basic Law of Science and Technology, which the Diet passed in 1995. EU has also similar trends in focusing its technology policy. These trends is also true to newly industrialized countries in Asia. For example, Korea established its G7 project in 1992 for aiming to catch up technologically to G7 group of advanced nations by 2000. Other Asian countries, such as Taiwan and Singapore, are moving forward to this trend.

Although all of these policies includes some measures to promote basic research and educational upgrading, which have been regarded traditionally as a government role in technology policy, it might be interesting that they also include some measures to promote commercial level or so-called "pre-competitive" technology more or less for specific industry through cooperation between government and industry.(*1) These kinds of cooperation, especially through government-industry joint research consortia, are often created to promote growth of a specific high technology industry, in which high productivity and market growth are expected.

One of the most typical industries is the semiconductor industry. Following the success of Japanese VLSI's project in 1977–79, at least in terms of the fact that industry began to grow after the project, many government-industry consortia were established around the world in the latter half of 1980's — about a decade after the VLSI project. In

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*1. Government intervention on "pre-competitive" technology tends to provoke the argument on effectiveness of "targetting" or "picking up winners". In this paper, I will focus on growth pattern of high performance industry and on its relationship with government by using semiconductor industry as a case study, rather than on justification of targeting on semiconductor industry. Probably two points should be discussed to address this latter question, which this paper will not mention much.
1) Effect of high productivity and high growth industry on national economic growth.
2) Imperfect market mechanism and role of government-industry relationship.
the United States, SEMATECH, a semiconductor consortium participated by 14 firms originally, was formed in 1987. (*2) In the EU, the Joint European Submicron Silicon Initiatives (JESSI), a eight year project participated by 28 companies, began in 1989 as a destination under the European Research Coordination Agency (EUREKA). In Korea, the 4M project started in 1986, and subsequent projects succeeded the project. In Taiwan, Taiwan Submicron Consortium (TSMC) project, a four year project participated by 13 local firms, started in 1990, relatively later.

Because of these government consortia or not (*3), two prominent changes have happened around the late 1980's and the early 1990's; the resurgence of the United States based industry against that of Japan and the emergence of Korean based industry. Figure I-1 shows the change of world market share by US based industry, Japan based industry, and Europe and Asian based industry.

Figure I-1. World Semiconductor Share by Industry

![Figure I-1. World Semiconductor Share by Industry](image)

(Sources) SIA

How these government-industry research consortia played a role in these

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*2. One of the objectives of SEMATECH is national security, which this paper does not discuss.

*3. Government intervention to the semiconductor industry in this period was not limited to technology policy. One of the most famous examples is the US–Japan Semiconductor Arrangement. Although this arrangement’s effect on industry might be enormous, this topic will not be investigated much in this paper.
"competitiveness" changes? (*4) At least, it might be said that US and Korea's consortia were successful in terms of market shares have increased. However, there are numerous debates over this causal relationship between these government technology policies and these competitiveness changes. For example, as for the SEMATECH case, proponents for this kind of consortia, such as trade associations like Semiconductor Industry Association (SIA) and government sides like Government Accounting Office, tend to stress that there were wide range of beneficial impact on the U.S. semiconductor industry and its semiconductor materials and equipment (SME) industry (Howell et al. (1992), GAO (1992), Corey (1997)), indicating that the government policy and competitiveness change is coincident. On the other hand opponents such as non-members of SEMATECH and anti-industry policy-ists insist that the resurgence of the U.S. industry was self-engineered, pointing out that emergence of small and medium enterprises in Silicon Valley and some SEMATECH's focused projects were failed despite huge government investment. (Dick, 1995). These debates are true to the Korean consortium. Some argue that Korean governments spending a lot of money for its semiconductor industry, which must have been giving huge impact on its development (Howell et al., 1992), while others argue that, comparing with other Korean industry such as steel and automobile, the development of Korean semiconductor industry was done not by government interventions but by themselves. (Hobday (1995), Kim (1997))

Basic difference of these views lies in the position of these consortia; Are they government laboratories or private laboratories? Basically, consortia are formed by private companies, and subsidized by government. Therefore, government side tends to regard them as a part of the government since it is the government who gives private firms an incentives for innovation by subsidies through consortia, while participating firms tends to consider it as a private since it is the private firms who is doing research, mostly out of consortia. Probably this kind of dichotomy is not useful to understand the role of consortia. Fundamental distinction between consortia's function and private firms' research activity is that consortia, which is by definition made up of many firms, tend to facilitate technological information exchange among firms, while simple aggregation of

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*4. In this paper, "competitiveness" refers world share of the industry, unless prompted. (see footnotes p8, p12)
individual R&D efforts do not. Considering this point, I will put two questions for analysing effectiveness of consortia. One is how this consortia's function as technological information exchange (linkages) "shapes" the industry's growth. This means that analysis must be made to find out the consortia's role as institutions for information exchanges and then for growth. The other is whether government subsidies are necessary to form these consortia. In other words, the cost for information exchange can be justified government subsidies to be poured into consortium or not.

Despite two extreme view of government-industry consortia mentioned before, majority of analysts of SEMATECH take a middle point of view. They point out many factors of competitiveness change, such as market, capital, technology, infrastructure (that is, SME industries) and conclude that SEMATECH was also one of the factor of these changes. (such as Angel (1994), Green (1996)) Their analyses might be accurate and also appropriate in a sense that they take whole surrounding industry structures into consideration in their analyses. However, they still seem to regard consortia as organizations funded by government input rather than as organizations for technological information exchange. They also seem to be lacking in comprehensive view of the role of technological information exchanges, which consortia can play as a force of technological development.

In this paper, three main questions will be put for analysing the effectiveness of consortia in the semiconductor industry.

i) *What was the causes of recent changes of "competitiveness"?*

Structural changes within/ outside the industry which have affected the competitiveness changes will be analysed especially in terms of technological information linkages, as well as of industry structure itself.

ii) *How did government-industry consortia affect these changes?*

This paper will analyse the role and the effectiveness of technological information linkage created by consortia in the competitiveness. Also the role of government in these consortia will be discussed.

iii) *What should the Japanese government do?*

The strategy of Japanese government to promote its semiconductor industry will be discussed on the basis of the current situation surrounding the industry.
Organisation of this thesis will be as follows. In next Part, theoretical review of the relationship between technological growth and technological information linkages will be made. In Chapter 1, the limit of traditional economic theory and the importance of information linkage will be discussed. Following that discussion, a mechanism of industry’s technological growth in terms of technological information linkages in industry structure – vertically and horizontally – will be presented in Chapter 2. Then in Chapter 3, the government role and its justification in creating technological information linkage through forming consortia will be examined.

In the Part III, the case study of semiconductor industry in the United States and Korea, in comparison with that of Japan, in the late 1980’s and the early 1990’s will be analysed. After summarizing the extent of analysis and its basic conditions in Chapter 1, Chapter 2 will review what had happened in the "competitiveness" changes, or world market share changes. The effect of macro-economic factor such as domestic market growth and exchange rate, and product specialization will be discussed. Chapter 3 will analyse the cause of competitiveness changes in terms of technological information linkages – vertically and horizontally, as well as of its industry structures. Chapter 4 will discuss how the government-industry consortia shaped these structural changes of technological information linkages through the examination of their organizations. The role and justification of government intervention through these consortia will be also evaluated.

Following these analyses, in Part IV, the conclusions will be presented as well as the recommendations for a Japanese government’s technology policy. This recommendation will be made for Japan’s new government-industry consortia, based on the discussion of recent changes of their technological information linkages.
Part II. Theoretical Review

Chapter 1. Traditional Theory for Competitiveness and Growth

(1) Comparative Advantage and Competitiveness

Most of the main stream economic theories are made of market mechanism, in which price and quantity will reach to the equilibrium, where the social benefit will be maximized. This static equilibrium will be attained through perfect competition with perfect information.

One of the economic theories which explain the "competitiveness" of industry (*5) is trade theory or theory of comparative advantage, which predicts industry's location among nations. In this theory, the determinant of industrial location in the world is the factor endowment, or the labor productivity in an simple case. Under the conditions of given productivity level including technological level, and free flow of labour movement, this theory predicts two main following points. One is that the industry with higher relative productivity in a nation compared with that of nations will have comparative advantage over the industry in other nations. Thus that industry will have total dominance (competitiveness) over the world, exporting the product for all the demand in the other nations' market. The other is that wages level of workers, thus GDP per capita, will reflect absolute productivity of this industry with comparative advantage, adjusted by this international trade through exchange rate mechanism. Through these mechanisms, this industry with comparative advantage will drive out an industry with no comparative advantage because of high wages, even if the latter industry has relatively higher absolute productivity than that of the former industry in other nations. This theory says that total benefit for each country will be maximized for all the country in the

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*5. This thesis does not mention the "competitiveness of nations". Although there is an official definition of "competitiveness of a nation" (Tyson, 1992), most of the scholars, especially economists, object to this notion, and insist that what really exists is the "competitiveness" of industry or the productivity of nation. (Krugman, 1994, Dollar et al., 1993)
Semiconductor is the one of the most globalized products, to which this theory seems to apply most. International transportation cost of semiconductors is negligible due to its value compared with its small size and weight. Tariff imposed on semiconductor is small in the major markets (Both in the United States and Japan, it is zero). In that sense, this industry are said to be under fierce international competition.

In this quasi-static theory, relative productivity is the only determinant of industry’s competitiveness. Therefore, in order to gain competitiveness in a growing industry, the speed of this relative productivity increase will be the most important determinants. A nation which accomplish this rapid growth of productivity in this growing industry will succeed in increasing its wage level, thus GNP per capita. Some may argue that in order to achieve this productivity increase, the basic factor such as educational level of human capital or basic governmental R&D is important and the place where governments can play their role. However, in reality it is mostly an industry itself who plays a role as forces to increase this productivity level, thus to develop economy and technology. Market mechanism theory including comparative advantage theory explains little about the role of this dynamic aspect of technology development mechanism.

(2) Problems of Traditional Theory

This theory of comparative advantage, which is based on productivity at manufacturing sites as a sole determinant, has mainly two problems in explaining the real world of "competitiveness" change of semiconductor industry, which is a highly capital and technology intensive industry.

One of the problem is that it assumes perfect information, which is not in reality. The theory of comparative advantage suggests that an industry with an advantage will be dominant over the world market, at least in one segment, as long as they have enough capacity to supply the world demand. This might be true in some sense that the United States and Japan were the only the countries (or at least as a base of firms) who produce semiconductor dominantly, and that product specialization of the nations is also proceeding in some segments as explained later. However, in reality, bulk of semiconductor products are still sold domestically. The semiconductor industry based in
the United States has about 60–90% market share in the United States, and Japanese industry has 70–90% market share in Japan.

Why does this kind of domestic advantage exist? One of the main reasons of this domestic advantage is imperfect information. Semiconductor has a variety of products; some of them are commodities with a set of specification (such as DRAM), but others are highly custom-oriented products, which need close communications between market and suppliers to be produced. In a sense, this can be a part of "transaction costs", which some institutionalists argue. Transaction costs are "the costs of specifying what is being exchanged and of enforcing the consequent agreement" (North, 1994), which can be applied to the wider ranges of transactions, including not only transactions regarding financing and labor supplying, but also those between market and suppliers. Since semiconductor is a highly technology intensive goods, in which technological information exchanges on its specification between their development teams of buyers and suppliers are vital for some segments, transaction costs tend to be high, and can be de facto barrier across borders even if transportation costs are low. Because of this transaction cost of technological information, the determinants of competitiveness is not only productivity at production sites but also degree of technological information exchanges between buyers and suppliers.

The other problem of comparative advantage is that the gap between perfect competition and the dynamics of technological development. Market mechanism may assume that perfect competition leads to most efficient productivity growth, but fail to explain why. It may be possible to explain the productivity growth by combining growth theory of economics, as represented by Solow's model. This model predicts that productivity growth can be attained by capital investment. Since this capital investment expansion is, in other words, diffusion of technology, which is embedded in its investment, this growth by capital investment will diminish, as explained as diminished marginal return of capital investment. Thus, it might conclude that growth of advanced countries will be slowed down while that of developing countries will be faster, as technology (investment) is diffused from advanced countries. This explanation might be in line with the theory of comparative advantage in a sense that many multinational semiconductor firms try to invest in some developing countries where labor cost is low. From developing countries' perspective, they can create their comparative advantages by acquiring and learning technology (and capital) as fast as they can from advanced
countries. This can be discussed from the standpoint of the concept of "competitive assets". (Amsden, 1996)

These two theories, market mechanism and growth theory, may explain diffusion effect of technology, but little about its technological development mechanism, which is main force of the industry in advanced nations. In the real world, firms of only a few nations, such as U.S., Japan, and Korea (and Europe to some extent) have succeeded in creating technology and achieved technological advantages by themselves. Their growth led by technological development are sometimes faster that that of developing countries, which is often led by technology diffusion from abroad, through, say, merely accepting technology through foreign direct investment, but having little capability to develop technology comparable with those of advanced countries. It seems that technological diffusion (technological information exchange) within in these advanced countries is triggering a new technological development of industry rather than diminishing its industrial growth. Although there are some recent theories of endogenous growth (Barro et al., 1995, Grossman et al., 1991), but it still seems to fail to address the mechanism of technological development; why some countries are successful in developing technology but why not other countries?

(3) Competitive Advantage and Technological Linkages

How are both of these imperfect information between buyers and suppliers (vertical relationship) and dynamic aspect of competition between firms (horizontal relationship) related to technology development at all? One of the most persuasive research on this dynamic change of national "competitiveness" of industry is "the competitive advantage of nations", which is advocated by Michael Porter. (1990) He did his research through studying many examples of thriving industries based on a nation in the world, and concluded that four elements, that is factor conditions, demand conditions, related and supporting industry, and firm strategy, structure and rivalry, known as his four diamonds, are the main determinants of competitive advantage of industry.

However his argument is relatively unclear in terms of relationship with traditional comparative advantage theory and recent theories mentioned before. Probably this is because Porter's argument mainly focus on the "existence" of components of industry
structure, such as market, supporting industry, and rivals, while these theoretical problems lie in "relationship" among market, supporting industry and rivals. In this relationship, it is important to know how firms (market, supporting industry and rivals) exchange technological information, since two problems mentioned above is related information or technological exchange/ diffusion.

In this paper, I will analyse the technological growth of industry both in terms of its development and diffusion, not only from the basis of Porter's argument on the existence of determinants but also from the point of view of "technological information linkages" which connect firms in industry structure. Technological information linkages (hereinafter technological linkages) are the secured or institutionalised information exchange channels in which firms can diffuse and acquire the technological information with each other. Since the activities or strategy of industry, the main players of technological development, will be greatly affected by these technological information, these technological linkages within industrial structure, as well as industry structure itself, must play an vital role of industry's technological growth. For that purpose, three aspects of technological linkages will be explained, as well as their relationship with Porter's four diamonds.

\( a) \) **Vertical technological linkage of industry**

This linkage is technological/ informational relationship between buyers (market) and suppliers. The relationship with Porter's "demand condition" and "related and supporting industries" are fitted in this aspect. Traditional economics assume perfect information in transaction, but in reality this relationship includes transaction costs on one hand, but it also can be a sources of technology through its vertical technological linkages.

\( b) \) **Horizontal technological linkage of industry**

This linkage is technological/ informational relationship between rivals. Porter's "rivalry" part of his determinants will be this aspect, although he rather focuses on its existence. In general, rivalry between firms are the main incentives to develop technology. However, the concept of rivalry is a little bit different from that of market competition, which traditional economics assume, is a little bit different from that of "rivalry". Rivalry has a relationship of some kind of technological diffusion as a form of direct/ indirect technological linkages between firms, while market competition in
economics only assumes price and product information exchange through market.

c) Basic factor linkage of industry

This linkage, which is related to Porter's "factor conditions", is the relationship with universities or other outside R&D organizations for the purpose of, say, educating engineers or acquiring results of basic research, although again he focuses its existence rather than its relationship. This factor, which is similar with national innovation system which Nelson (1993) describes, might be important especially for long-term development of industry as well as of total economy, but not be focused much in this paper.

In the following Chapter, these technological linkages within industry structure, especially vertical and horizontal linkages, will be discussed. Linkages other than these technological linkages, such as those of financial system or labor systems, will not be discussed. As same as Porter's argument, this paper will examine this growth mechanism in terms of industry based on a nation rather than in terms of nations as a location of industry, because it is firms rather than nations which have and develop commercial technology in general. (*6) Thus the question will be why an industry based on a nation can create technology faster and more efficiently than an industry based on others?

*6. In this paper, I will mainly discussed the competitiveness of industry which are based on a particular nation rather than industry in country as a production base. The reason of this is because it is firms who have and develop their technology, and most of the firms still develop technology at home. (most of foreign direct investment for manufacturing are in developed countries, which is a natural result of theory of comparative advantage.) However, it is true that this notion has two problems. (Reich, 1990, Tyson, 1991) 1) nationality of firms is blur. This causes problems on implementing national policy 2) effect of foreign direct invest to other countries on national economy needs further examination. These problems will be more important when JV or globalization of firms among advanced countries, which will be touched on briefly.
Chapter 2. Technological Linkage in Industrial Structure

(1) Economic Nature of Technological Development

<Market mechanism and technological development>

Although market mechanism itself does not address technological development clearly, it may include one of the most important premises to give firms an incentive to develop technology, which is monopolistic aspect of technology. (*7)

In a perfect market mechanism, firms with same technological level (*8) compete with each other by cutting prices. Through this competition, price will be forced to decrease to the point of equilibrium, where \( P=MC \) and the strongest group of technological level can survive. Since no profits are expected in this equilibrium (not in terms of accounting), this mechanism will force firms to seek profits by achieving technological development. In general, there might be two strategies for this. One is the cost-reduction strategy. By achieving low processing production cost (that is, lower \( MC \), including managerial cost) which other firms cannot achieve, firms will be able to gain monopolistic profit \( (P-MC) \times \text{market size} \). This is the case of process innovation. The other strategy is product differentiation. By seeking new market and products (including upgraded product quality) where there are few competing firms, they can also get monopolistic profit since there are few competitors. This is the product innovation process.

<Proprietary technology as monopoly>

In short, the principal force of innovation and technological development is the monopolistic profit, which can be earned by destroying market equilibrium, a conclusion

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*7. Probably, technology can develop not only by market mechanism but also other incentives, such as a strong leadership or initiatives. Government mission oriented research may be depending on this mechanism.

*8. Precisely speaking, technological level (productivity) must be measured by its relative aspects in an international competition, as comparative advantage suggests. However, this thesis focus on its dynamic aspect rather than its static comparison.
of perfect competition. These monopolistic profits can be sustained because some of these newly created technology, if not all, − either through process innovation or through product innovation − are proprietary to firms who innovated them. Some of the technologies, such as product itself and published technical documents and so on − non-proprietary technology/ information, may be available outside firms, but other parts of technologies such as know-how or tacit technology will be proprietary to firms and not available outside firms. This proprietary technology, which are mostly embodied in human capital or organization, is the most important part of technology for commercializing it into products. Since this proprietary technology is the source of sustaining monopolistic profits, firms try not to disclose it so that their profits will not be eroded away. In other words, the very fact that this proprietary technology can be protected will be an incentive for firms to develop technology. If firms see their own proprietary technology which they create will be diffused soon, they will not have an incentive to invest it.

<Diffusion of technology and continuous development>

However, this monopolistic profit cannot be always sustained for a long run. There are two possibilities of erosion. One is the diffusion of technology, and the other is rival’s own efforts of technological development. Since technology is a kind of information, which can be easily transferred to other firms with little cost, it will be diffused at least in the long run, despite firms’ efforts to hide it. Non-proprietary technology/ information can be easily diffused, but even some of proprietary technology might be transferred by way of, say, changing jobs of its engineers or other means. Due to this diffusion, they may lose their monopolistic position to their rivals who acquired these technologies. In this sense, rivals might be relatively easy positions to catch up to the first runner’s position, since they can develop their own proprietary technology at least by taking first runners’ non-proprietary information into account. Partly because of this diffusion of some of their technology, and partly because of this rivals own efforts, firms’ monopolistic position may be eroded by rivals’ technological emergence.

This possible emergence of rivals may not be preferable for the firms but for society as well as for a next stage of technological development. Since this possible existence of rivals might lead their monopolistic positions back to market equilibrium, it will be an incentive for the firms again to keep developing their technology continuously.
so that their monopolistic profit will not be eroded. In sum, the mechanism of technological development is the continuous process based on competition among rivals, in which technologies are created by incentives of monopolistic profits and then this monopolistic positions are destroyed by technology diffusion.

<Questions>

Basically this technological development might be interpreted as a trade-off between protecting technological monopoly and promoting technological diffusion. Protecting technological monopoly will give an incentive to develop new technologies, but this is still a monopoly and not preferable at least from the static view of societies, since technology can be utilized by any other firms with few additional costs. Promoting diffusion might be preferable in a sense that it will raise technological level of the whole industry by learning its technology, but firms may lose incentives to develop technology. Probably, the optimal solution might depend on situations of the industry. For example, emerging industry which needs technological breakthrough may require incentives, while promotion of technological diffusion might be preferable in a relatively matured industry with a few dominant firms. Especially developing countries may need to promote technology diffusion from abroad.

However, in reality, firms in some countries seem to have succeeded in both developing and diffusing their technology. For example, it is not only NEC but also all major 10 firms who rapidly grew after 1980's in Japan. It is not only Samsung but also other two Korean firms who began to grow in the late 1980's. It seems that technology has been widely spread throughout/within each nation, while firms have a strong incentive to develop their technologies. Why are both of these incentive and diffusion are strong in some countries but not in other countries?

Therefore, it may be worth considering a possible system which can achieve both incentives and diffusion. The key of this system lies in technological linkages, which regulate technological information flow. The effective system must have some technological linkage in which the distribution of technological information is institutionalized so that firms in the industry can both develop and diffuse their technology effectively by influencing with each other. In this regard, two points can be raised. First is the role of non-proprietary technology/information. Is this kind of non-proprietary technology/information diffusing effectively? How does this information play
a role in technological development? These questions might be important especially between rivals (in horizontal relationship). Second point is the possibility of cooperation in proprietary technology. Is it possible to cooperate in exchanging proprietary technology each other without hurting incentives? How about the cooperation in vertical relationship? In the following sections, these questions will be discussed further from the point of vertical and horizontal technological linkages.

(2) Vertical Technological Linkages

<Imperfect information – domestic advantage>

As mentioned before, domestic industry is more closely related with domestic market than with foreign market because of imperfect information across the borders, which can be a de facto barrier as a part of transaction cost.

The reason of this imperfect information across borders is the reverse view of relatively strong technological linkage between market (buyers) and production (suppliers) within domestic industry structure. As mentioned before, semiconductor is not an unique product but diversified products, which cannot be substituted with each other. Each product has its own technical specifications, which are required by its customers (buyers) and which tends to be changed often because of the change of customers’ requirement. In order to develop and supply the products which meet this requirement with flexibility, suppliers must have close connections or linkages with its customers, by sharing technological information with each other.

This technological information is not always equally shared to all suppliers in the world even in an age of telecommunication and globalization, although these developments might have a great impact in the future. Even the language difference between countries might matter. In reality, bilateral negotiations between buyers and suppliers with face to face always play important in closer information exchanges, thus geographical location of product managers or engineers (either in headquarters, factories or laboratories) and customers tends to be a vital determinant in this regard. These closeness will contribute to the swiftness to change following the change of customers requirement or market needs. In other words, domestic firms have an advantage in terms of correcting imperfect information and acquiring the purchase contract in domestic
market. Even in a domestic industry, firms with strong linkages with market will have
an advantage over rivals and be able to get monopolistic profit. This is the reason why
firms try to do its marketing efforts.

One of the way to decrease this barrier across borders and thus to reduce
transaction cost is to standardize technological specifications of products. Standard is a
certain set of technological specification, which connects between buyers and suppliers.
In general, standardization of a product is preferable for both supplier and buyers, since
standard will create efficiency not only in trade (transaction) by reducing transaction cost
but also in technology development; buyers and suppliers will be able to develop
technology and products based on existing standards. Thus standards will be embedded
and fixed in the industry structure. However, there might be a problem in terms of
flexibility; once a standard has established, it is difficult to change unless another strong
technological breakthrough happens.

If standardization proceeds, this technological linkage will not be necessary as
before, as long as the standards are open to any firms. Standard can be created not only
by governmental committees but also by market forces as a de facto standard. Actually,
some segments of semiconductor products are (de facto) standardized and traded
worldwide. For example, some products with a character as a commodities (such as
DRAM, which even has a spot market) or those with de facto standard (such as Intel's PC
micro-processors) might be easy to be sold and be purchased without close
communication, thus do not need closer technological linkage between market and
manufacturers.

However, technological linkages still matter for most of semiconductor products,
such as ASICs, which are custom-oriented by nature, thus need close relationship with
customers. For these products, technological linkages are more essential than the
standardized products, and competition among rivals will be not only based on price or
quality but also on its meeting with requirement of customers and its flexibility to adjust
to its requirement.

This kind of technological linkages is stronger within domestic firms than firms
across borders, thus it plays a role as a barrier across borders and a source of imperfect
competition, which can give domestic manufacturers an advantage. This can be critical
especially in a product in which technological development is rapid, as can be seen in high
-technology areas such as semiconductors.
This technological linkages of exchanging information is useful not only to reduce transaction costs but also to promote its technological growth or development. In general promoting diffusion or fusion of technology diffusion will not undermine firms' incentives even if it includes proprietary technology, since usually downstream industry or upstream industry are not "rivals" and producing different products from that of the industry. Rather, even non-proprietary technological information can be useful for firms since firms which received the information will be able to come up with ideas on new products and recognize growing market more swiftly than firms based on abroad.

This effect of technological linkages on technological development can be seen in both downstream industry and upstream industry. Porter (1990) describes in his "demand condition" part that sophisticated and demanding buyers pressures local firms to meet high standards in terms of product quality, features, and services, while explains in his "related and supporting industry" part that supporting industry can be also a source of technological seeds since "competitive advantage emerges from close working relationship between world-class suppliers and the industry" and "suppliers help firms perceive new method and opportunities to apply new technology." In this sense, domestic presence of strong downstream and upstream industry in its vertical industry structure is also important, as well as the linkages that bridge between the industries.

Since this technological linkage can be beneficial for both buyers industry and suppliers industry, industries connected with vertical technological linkages tend to co-develop technologically with each other. An industry which are connected with strong industries through this linkage will be able to develop their technology, and this strong counterpart industries (either of downstream or upstream) will also be able to strengthen its technological level in return. This process will create dynamics of vertical co-development of both buyers industry and suppliers industry.

This technological co-development tends to be accompanied with market growth for each industry (co-development of market and technology), accelerated by this technological linkages and linkages of (usually domestic) trade. For example, productivity growth based on technological development stimulates new market growth in a country/region connected by the linkage, while market growth will stimulate technological development through increasing competition with new entrants or through attaining
learning curve/ economies of scale. Even from macro-economic view, productivity increase contribute income increase, which leads to market growth. This may be a part of mechanism of creation of "clustering", which Porter (1990) pointed out.

<non-proprietary technological linkage >

This vertical technological linkages in terms of non-proprietary technology tends to be strengthened voluntarily since diffusing non-proprietary technology to buyers/suppliers can be a source of monopolistic profits, thus incentive to develop technology. Firms try to diffuse their non-proprietary information on technological specification of their products as a form of their marketing (or procurement) efforts. Since their products is the results of their own proprietary technology, the success of this marketing efforts through expansion of technological linkages can lead to monopolistic profits, especially if its products specifications are based on monopolistic feature of proprietary technology. This is important in a new or rapidly growing industry, since they can get monopolistic advantage for a while by creating and expanding de facto standard which is linked with their own proprietary technology, and this advantage can be sustained until rivals can catch it up.

Usually, the speed of dominating in de facto standards is slower than that of diffusion of technology or catching up to the proprietary technology by other rivals. In this case, created de facto standards may be profitable for first inventor, but can be diffused easily and allows free entry of new entrants. Therefore, firms have to develop continuously their proprietary technology and to do marketing the product. In this regard, this is also a continuous innovation process based on competition among rivals, in which technological de facto standards in vertical relationship are created by incentives of monopolistic profits and then this monopolistic position is destroyed by diffusion of this standards.

However, sometimes, speed of growth of de facto standards might be faster than that of diffusion of technology, partly because of network effect of standards in micro-economic terms, but mainly because of highly protected proprietary technology which is linked strongly with standards. In this case, firms will succeed in getting total monopoly (which are sometimes called as "techno-poly"), by keeping this de facto standard intact from rivals. Intel's PC micro-processor is a typical example. The Economists (1996) describes that "Technology is about standards. To succeed with consumers, one firm's
gadget often has to work with other gadgets from other firms. Technology moves so quickly that standards set by committees usually come too late. Instead, the industry organizes itself around *de facto* standards championed by single firms with the clout to make them sick — as, for instance, Intel has done with micro-processors." This will be preferable as an incentives for creating technological linkage through marketing as well as developing their proprietary technology, but might not so in terms of diffusion or rivalry.

<Proprietary technology exchange>

On the other hand, vertical technological linkage as proprietary technology exchange is not always voluntarily created. First of all, in most of the cases, both of industries do not always need the counterpart's proprietary technology or direct cooperation, simply because these are technologically independent. In this case, vertical technological linkage between buyers and suppliers might be based solely on its specification and quality of products. However, in some cases, proprietary technology of counterpart industry are so interdependent with its own proprietary technology that it can be an important source of technological innovation. The relationship between semiconductor industry and its equipment industry is a typical example, as von Hippel found that semiconductor firms "developed all of the process machinery innovations involved in the initial commercial practice of a process step and more than 60% of the major and minor improvements to that machinery." (von Hippel, 1988) In these industries, this transfer or fusion of proprietary technologies will be vital for its technological development.

Even in this case which proprietary technologies of both industries are mutually useful, these cooperation of exchange is still not always voluntarily created, since there exists a free-rider problems. Let's consider the case in which buyers Firms A and Firm B are independently thinking about cooperation with suppliers to upgrade suppliers' technology by spending 4 units each of firms' expense, and expecting 6 units of gain by market increase, which will be divided by both firms. In this case, the benefit of upgraded products may be free-rided by rivals, since supplier can sell their products to other rival buyers. Table II-1. shows this situation of prisoners' dilemma. Of course, the success of this cooperation may be depending on the amount of return from cooperation, it is important to know there is a case in which trust or some institutional structure that overcomes prisoners' dilemma might be necessary to make cooperation
successful.

Table II-1. Prisoners’ Dilemma: Cooperation or non-cooperation with suppliers

<table>
<thead>
<tr>
<th></th>
<th>Firm B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cooperate</td>
</tr>
<tr>
<td>cooperate</td>
<td>(2, 2)</td>
</tr>
<tr>
<td>non-cooperate</td>
<td>(3, -1)</td>
</tr>
</tbody>
</table>

Moreover, it might be important to note that this case does not assume diffusion of proprietary technology but only of technology as a form of products. If this vertical linkage of proprietary technology is regarded by firms as a channel for diffusing their own proprietary technology to other rival firms, it will be more difficult to form this kind of vertical cooperation. In this sense, some mechanism, such as vertical keiretsu, to protect proprietary technology from being diffused would be useful.

(3) Horizontal Technological Linkage

<Domestic advantage>

Market mechanism assumes information on market is available perfectly, but it usually does not imply the availability of direct information on competitors. In market mechanism, firms are regarded as players who react to market information. However, in reality, technological information on rivals is always available not only through market but also through direct or other indirect ways. Although it is somewhat difficult to obtain proprietary technology of rivals since firms try to disclose it, non-proprietary information on rivals are relatively easily available. For example, as for indirect technical information exchanges (diffusion), mediums such as magazines or newspapers for specific industries, trade associations, and governmental agencies play roles as dissemination media of
technological information. Vertical technological linkages, either through downstream (market) or upstream, also can be channels to disseminate technological information of firms to rivals. These technological information might be somewhat fuzzy to know what the rivals are really doing. As for the direct technological information exchange, for instance, personal contact at academic societies and sometimes even hiring former employees of rivals can be sources of technological information of rivals. This direct information exchange might be clearer and useful to know what rivals are doing than that of indirect exchange (diffusion), but still somewhat ambiguous because these exchanges tend to be too temporary and too partial for firms to acquire whole system of complicated proprietary technology of rivals.

This kind of technological information flow between competitors, that is horizontal technological linkages, are again more strongly connected among domestic firms than those between domestic firms and foreign firms. Although not always the case, but in generally, indirect media such as magazines or associations mostly focus on domestic firms. Indirect horizontal linkage through vertical linkage is also rather domestic since industries in vertical linkage are connected more strongly with domestic firms except some commodities-like products as mentioned before. Therefore domestic firms in general tend to compete not with foreign firms but rather with domestic firms themselves. Even for direct information exchange, exchange within domestic firms is more frequent than that of across-borders. For these reasons, horizontal technological linkages among domestic firms are stronger than that of across borders.

<Co-development of firms in rivalry>
These horizontal technological linkages, mostly those of non-proprietary technology, are mutually beneficial for firms to develop their own technology since this will facilitate rivalry between firms. As opposed to pure market mechanism, in which firms react only to market information, this linkage may enable firms to interact with each other swiftly and flexibly to progresses of rivals' new technological development well before the technology is commercialized into products. In this sense, these linkages may be especially important in a fast growing industry since it may be too late for firms to catch up rivals after rivals have succeeded to produce new products. In sum, this linkage will enhance market competition into technological competition, and enable firms to co-develop their technologies with each other. Porter (1990) described that strong domestic
rivals create particularly visible pressures on each other to improve.

This pattern of co-development might be different by its horizontal structure. First let’s consider the case of competition among large firms with homogeneous nature, because of which firms tend to have a same technological goal (pursuing a single growing segment). In this case, thanks to this technological linkages, firms may be able to guess what rivals are trying to do, but not to know the exact level of rival’s proprietary technology since information is imperfect due to high rivalry. Even if the information is imperfect, this kind of technological information will be useful for firms to, say, modify their R&D efforts on the right track. Moreover, their efforts on technology development tend to over-react to these information on rivals since they have to have an enough technological advantage over their rivals in order to create technology based monopoly. Yoneyama et al (1995) explains that this kind of indirect and "fuzzy" non-proprietary information have facilitated Japanese firms’ rivalry in the DRAM development up to achieve over-spec quality because firms imagine and outguess the level of rival firms so excessively that the deviation from real level of rival firms is amplified. In this sense, technological development of homogeneous firms in a focused segment will be enhanced by "fuzzy" and indirect non-proprietary information.

Next, consider the case in which competition of relatively small firms under presence of large firms. In general, they will try to diversify their technology and products pursuing niche markets or new markets, since they know they are not able to compete with large firms even if they do not know the actual level of large firms’ proprietary technology. Therefore, direct information exchange among small firms can be prevalent since small firms might be so diversified that they are not always rivals each other and single firm cannot always develop a technology by itself. They may be also able to get clearer information on large firms through direct information exchange because small firms are not always rivals for large firms. In return, the success of these small firms can be a source of new idea for big firms as well as small firms technological development because of its diversity. Thus diversified technological development will be facilitated by the clearer and direct information exchange based on diversified horizontal structure.

<Non-proprietary technological linkage>

At least, some of this non-proprietary technological information will be diffused
inevitably, especially through vertical linkage or press release (partly for financial purpose). Then question will be whether firms try to exchange these information voluntarily with rival firms or not.

This might be also a prisoners’ dilemma. Even if firms know that information exchange without losing its proprietary technology are mutually useful, they does not always disclose their non-proprietary information voluntarily, since there again exists a free-rider problem. Let’s consider the case in which two rivals, Firms A and Firm B, decide to whether disclose their general outlines or prospect of the results of on-going each research project or not. By disclosing these information, firm may lose, say, 4 units by rival’s surge, but due to co-development process, win 6 units of market increase, which will be shared with rival firms. Although disclosure by both firms will be beneficial for both firms, each firm tend to free-ride other firms’ disclosure. Table II-2 shows this situation of prisoners’ dilemma. In order to make information exchange successful, trust or some institutional structure might be necessary.

Table II-2. Prisoners’ Dilemma: Disclose or non-disclose non-proprietary information

<table>
<thead>
<tr>
<th></th>
<th>Firm B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>disclosure</td>
<td>non-disclosure</td>
</tr>
<tr>
<td>disclosure</td>
<td>(2, 2)</td>
<td>(-1, 3)</td>
</tr>
<tr>
<td>non-disclosure</td>
<td>(3, -1)</td>
<td>(0, 0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>loss by disclosure</td>
<td>..... 4 per firm</td>
</tr>
<tr>
<td>return from disclosure</td>
<td>..... 6 per disclosure for both firms (3+3)</td>
</tr>
</tbody>
</table>

Again, if return from information exchange is large enough, these cooperation may be successful. Actually, for instance, some firms try to coordinate among themselves to disclose their information in order to create de facto technological standard. However, firms also tends to be afraid too much that these information exchange might be accompanied with leakage of their proprietary knowledge, since the border between non-proprietary technology and proprietary technology is ambiguous.
As mentioned before, firms do not want to diffuse their proprietary technology in general since these are the sources of their monopolistic profit. However, as long as firms have incentives to develop technology, proprietary technology exchange might be preferable in terms of social benefit because it will diffuse technology. Are there any cases in which horizontal proprietary technology exchange will be self-organized?

Many policy-makers as well as analysts suggest that joint research is useful because economies of scale or scope can be attained by putting different technological sources together. (for example, Grossman et al., 1986) This may be preferable from the point of static view of society. However, on the other hand, from the view point of firms, this may not always be true. First let’s consider a domestic large-scale joint research. Indeed firms may expect market increase due to new technologies created by scale or scope economies of joint research. However, they may lose all of their profits because competition after joint research will be harder if proprietary technology of all firms become identically same due to sharing of all of proprietary technologies of each individual firm. (Choi, 1993) In other words, even if market size is expected to increase, profit \((P - MC) \times \text{market size}\) will be zero, as long as \((P - MC) = 0\). The only advantage of joint research in terms of profit may be the competition against non-member firms, especially against foreign firms. Therefore it is difficult for firms by themselves to form large-scale joint research for the purpose of exchanging proprietary technologies unless there are enough expectation of market increase, especially opportunity to export products or to expel foreign imports.

These discussion may be true to small-scale or bilateral joint research. However, a possibility that small-scale or bilateral research cooperation will be created voluntarily may be higher than that of large-scale joint research because its degree of those argument may be different. First of all, small firms alliance can be easily formed since they have huge market to exploit and alliance will not diffuse their proprietary technology to most of other firms.

Second, as for the bilateral alliances, actually growing number of alliance are formed after 1990. Main reasons of this change are both pressure to share the expense and risks of rapidly growing investments in R&D and tendency towards greater design and market specialization. (Angel, 1994) Figure II-1 shows this.
However, there are also reasons that they can form alliance despite its difficulty. First, they do not always intend to exchange all the proprietary knowledge. In most cases, they just intend to complement some of the technologies with each other. Some of the agreement are just for sales cooperation and exchange information. Second, they do not always expect severe competitions after alliances. In addition to different product line of allied firms, most of the counterparts are not domestic rivals but foreign firms (Angel, 1994), which in general compete at foreign market.

Table II-3. Technological Linkage in Industry Structure

<table>
<thead>
<tr>
<th>竖向联系</th>
<th>水平联系</th>
</tr>
</thead>
<tbody>
<tr>
<td>非专有技术</td>
<td>市场机制假定完美</td>
</tr>
<tr>
<td></td>
<td>交易成本 - 标准</td>
</tr>
<tr>
<td></td>
<td>非事实标准 &amp; 技术联盟</td>
</tr>
<tr>
<td>专有技术</td>
<td>囚犯困境</td>
</tr>
<tr>
<td></td>
<td>可能性泄露</td>
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</tbody>
</table>
Chapter 3. Government Role in Technological Linkage of an Industry

(1) Traditional Role and Intellectual Property Rights

Traditionally, and especially in the United States, government intervention in technological area have been limited to education and basic research as well as mission oriented research. Education and basic research, which are to improve basic factor endowment of country, are traditionally justified to be intervened since they may tend to be under-invested by market mechanism. Indeed, these areas might be important for a long term economic growth.

However, the government role in technology for economic growth has not been restricted to these basic areas but also included commercial level of technology. For example, almost all advanced countries has a tax reduction system for private R&D expenditure. Besides, the most influential government intervention in terms of technological linkage is the protection of intellectual property rights (IPRs). Patent system is a typical example of IPRs. Chip design protection was also introduced in the 1980's (1984 in the U.S, 1985 in Japan, and 1992 in Korea) Basic idea of these IPRs is to promote diffusion of its technological knowledge after its invention in return for giving legal monopoly for its use in order to give incentives to firms to invest in R&D. The basis of this idea is to find a optimal solution in a trade-off between incentives and diffusion: diffusion of technological knowledge will be socially beneficial, while monopoly should be given legally to inventor firms so that firms might not lose incentives to invest in research and development by a free-rider problems. This is a quite different feature from physical investment, in which no free-rider problems would be occur as long as the ownership of property is clear.

In general, intellectual property rights system might be a well-organized mechanism. However, it does not mean that this system has no defects. Three problems can be raised. One is that intellectual property rights cannot protect all useful knowledge or proprietary technologies. For example, as for the case of semiconductor, patent system can protect "novel", "useful", and "not obvious" technology and chip design act can protect chip design. However, knowledge such as know-how or tacit technology,
which may not be, say, novel but still useful, will not be protected by IPR systems. Since these parts of proprietary technology are critical for actual manufacturing, firms still try not to disclose them. In this sense, some asymmetry in degree of protection might exist between firms with strong manufacturing technology, which is mostly composed of tacit knowledge, and firms with strong designing technology, which products itself never fail to be protected.

Second, legal monopoly rights might be preferable as a incentive for firms but not from standpoint of social benefits. As usual story of market mechanism, monopoly is inefficient in terms of dead weight loss; the decrease in consumer surplus will be larger than the gain of producers (or inventors). This monopoly can be large especially in software industry (chip design for the case of semiconductor), in which its de facto standard tend to connect market with proprietary technology. Since this de facto standard itself is protected by intellectual property rights, a firm which succeeded in creating this de facto standard may develop into so-called "techno-poly", as mentioned before. In fact, all of "techno-polists" the Economist (1996) picked up in its article are firms based software technology. (Microsoft (PC operating system), Intel (PC micro-processor), Cisco (internet routers), IBM (mainframe software), and Intuit (personal-finance software) Of course it is possible for rivals to produce compatible software, but there still exists extremely high barrier for them to enter the market because software is so complicated system that an organization with experience (proprietary technology) of previous version of software has an overwhelming advantage over late-comers to create next version of upgraded and compatible software.

Third, over-competition or duplication might happen. Since patent is the game of winner-takes-it-all, in which monopoly is given to the first inventor (or precisely speaking, to first file applicant in most of countries, including EU, Japan and Korea, but to first inventors in the U.S.), firms try not to disclose, say, the data or idea of R&D projects during their research and before they file their application. In this period, firms tend to hide any information regarding its research project and to compete with each other excessively to get first prize. (Barzel, 1968, Suzuki et al, 1986)

At least from theoretical point of view, "purchasing" knowledge, especially software, from inventors by government (state) can be a superior mechanism, although this system is difficult to be implemented. (Noguchi, 1974) The basic idea of this system is to require governments to purchase useful idea from inventors and then diffuse it to the
public, that is, tax payers. This system may solve these three problems inherited in IPR mentioned above, but in reality as easily imagined, it is difficult to implement this system, say, to evaluate price of inventions.

(2) Role of Consortia and Comparison with Intellectual Property Rights

At least from theoretical point of view, forming consortia can be one of the alternatives or complements to IPRs. Basic idea of consortium is similar to IPR. Consortia in general assumes to do research efficiently through collaboration, but it also implies to diffuse the result of research created by each firm's own proprietary technology to members firms in return for giving mutual gain each other, like a cross-licensing in IPRs. In some cases, the result of research may be diffused to outsiders in return for government subsidies, like "state purchase of knowledge" system.

This consortium system has some advantages over intellectual property rights system. First, at least theoretically, all the technological knowledge and information, including not only know-how and tacit technology but also non-proprietary technological information, can be shared at least within members even during research. This is a quite different feature compared with that of IPR system, in which only IPR related technological knowledge will be posted on the file of patent offices of government after its inventions. Depending on its arrangement, consortium can diffuse some of the knowledge and information to outsiders as well, either through government ownership of IPR, through publication, or through forms of products. In these cases, government subsidies might be justified.

Second, no monopolistic rights are established in general as long as the number of member firms is large enough. As for technology related intellectual property rights, of course, this monopolistic features also depends on the arrangement of IPR, such as its ownership (inventor owned, joint-owned, or government owned) and its exclusiveness (exclusive or non-exclusive), but as long as these technologies are fruits of collaboration, its monopolistic features will be arranged to be reduced, say, by way of joint-owned. As for the non-IPR related technologies and information, which are important part for manufacturing, these technologies/ information can be shared among members so that monopolistic profit will be diluted.
Third point, which is raised by most analysts who advocate the usefulness of consortium, is its efficiency because consortium’s feature as no duplication and significant effects of economies of scale/scope as opposed to those of IPR, in which over-competition will be expected. This is the same with the discussion mentioned previously as a good side of large-scale joint research.

Those above are the good sides of consortium. As can be seen, consortia in general emphasizes on diffusion, while IPR on incentives. Because of this, there are also some problems in reality. Two main problems can be raised. One of the main problems of forming consortium is a free-rider problem within members. Firms may want to participate in joint research if created, but they may just want to free-ride new technology without disclosing their own technology. A member, expecting other members to do their own research and hoping it can get their results with free, will lose incentives to do research by itself, even if it knows collaboration is mutually beneficial. Because of this prisoners’ dilemma situation, rivalry to develop technology in consortia, thus effectiveness of consortia, may be reduced considerably.

The other main problem is, as discussed at the section of large-scale horizontal proprietary technology exchange, leakage of proprietary technology (especially know-how and tacit technology) to rivals might be tremendously fatal to their profit. Although these loss of leakage might be offset by mutual gain from other firms’ proprietary technology at least from social perspectives, these proprietary technology exchanges might be negative in total from the point of views of every firm’s profit. Due to this difference between objective of society (or government) and that of firms, firms may feel no incentives to exchange their proprietary technology with rivals unless large enough economy of scale/scope can be expected. It might also suggest large sum of government subsidies and strict enforcement of exchanges are necessary to make it. These two problems are in line with Porter’s argument (1990), saying that role of cooperate research is limited since it will decrease rivalry.
Table II-4. Basic Comparison with IPR and Consortium

<table>
<thead>
<tr>
<th></th>
<th>Intellectual Property Rights</th>
<th>R&amp;D Consortium</th>
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<tbody>
<tr>
<td><strong>Object</strong></td>
<td>a part of proprietary knowledge (patentable knowledge,</td>
<td>all of proprietary knowledge (including know-how,</td>
</tr>
<tr>
<td></td>
<td>chip design)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diffusion</strong></td>
<td>to all (not for commercial use) after file application</td>
<td>mainly to members during research</td>
</tr>
<tr>
<td></td>
<td>(after invention in the US)</td>
<td></td>
</tr>
<tr>
<td><strong>Incentive</strong></td>
<td>monopolistic profit</td>
<td>mutual gains</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Effectiveness</strong></td>
<td>over-competition</td>
<td>economies of scale/ scope</td>
</tr>
<tr>
<td></td>
<td>monopolistic aspect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(techno-poly)</td>
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</table>

(3) Things to be Considered: Substitute or Complement?

As discussed above, theoretically, governments can be justified to intervene commercial technology exchange through creating R&D consortia as they do through IPR. However, it is true that government intervention through consortia is not always effective for technological development. Government role in horizontal proprietary technology can be summarized in two points. One is whether diffusion of the fruits of research to non-members is expected or not. As Cohen (1994) mentioned that the higher the spill-over rate to non-members is, the larger the government subsidy is needed to compensate the loss of technology. In this regard, the government role here is as if like state purchasing technology system for non-members. The other role is to compensate the dissolution of monopolistic aspects of proprietary technology. This part of subsidy will be an amount of remainder after subtracting the effect of economies of scale/ scope from current total profit due to its proprietary technology.

In both of case, government have to subsidize it so that firms will not lose their
incentives and that consortia works effectively. However, as theory suggests, the latter part of government role may be difficult to be attained, since it seems to cost too much. Extremely speaking, it is clear if we consider the case when government subsidizes the total sum of profits of semiconductor industry, although not all of them are due to proprietary technology that can be diffused. From this regard, the government intervention in proprietary technology within horizontal linkage seems to be too costly and also difficult to implement. In this regard, consortia might not be able to be a substitute of IPR in this area.

On the other hand, as mentioned before, one of the most important features of consortium is its broad range of technology it can deal with, and its deep linkage of technological information exchange it can create. The coverage of technological knowledge of consortia includes not only IPR-related technology or other proprietary technology such as know-how or tacit technology but also non-proprietary technology/information, which is still useful for firms' strategy and technological development. The depth of technological information exchange that consortia can promote might be near perfect both vertically and horizontally. Apparently, these close linkages created by consortia will affect their rivalry/incentive and availability of technology. In this sense, consortia might not be able to substitute of IPR in horizontal proprietary technology area due to its emphasis on diffusion, but it may able to play a role as a complement of IPR by creating technological linkage of other three areas out of our areas of matrix (vertical - horizontal * non-proprietary - proprietary) I mentioned before. For instance, consortium might be able to create vertical linkages, which tend to need transaction cost and to be trapped into prisoners' dilemma, unless some appropriate institutions are created. It might also be able to promote information exchange of non-proprietary at horizontal level despite its prisoners' dilemma situation, and to give a clue of developing new technology for all of members.

This suggests that the effectiveness of consortia can be varied depending on how it can create these technological linkages in these three areas, as well as horizontal proprietary technology exchange. Also the effectiveness in these three areas might be different from its industry structure, since its horizontal and vertical structure is different from country by country. In the following Part, the case study of semiconductor will be discussed from this point of view.
<table>
<thead>
<tr>
<th></th>
<th>vertical</th>
<th>horizontal</th>
</tr>
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<tbody>
<tr>
<td>non-proprietary</td>
<td>(market mechanism)</td>
<td>transaction cost?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>proprietary</td>
<td>prisoners' dilemma?</td>
<td>monopolistic features?</td>
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Part III. Analysis of Semiconductor Industry

Chapter 1. Extent of Analysis and Basic Conditions

(1) Extent of Analysis

In this Part, the semiconductor industry in the United States and Korea, as compared with that in Japan, in the late 1980's and the early 1990's will be discussed. These periods were the time when the United States industry was said to regain their "competitiveness" and the Korean industry gained the "competitiveness" in the world, while Japanese industry lost it. These periods are also the time when the governments of both countries intervened the industries through their own technology policies; in the United States, it is mainly SEMATECH, and in the Korea, it was the 4M project and its subsequent projects, while in Japan there were no such projects that aimed directly to improve semiconductor technology of the industry. (*9)

Main focus of this paper is to find out how technology was developed in their industry structure, which is supposed to be an internal force to develop technology spontaneously. Without saying, so-called "competitiveness" will be influenced by many factors. This chapter will briefly summarize the possible effect by factor conditions of basic technological level (such as human resources or educational level, and basic knowledge resources) and of capital resources below. Although these factors might be important, I do not focus on these much, since I assume that,

i) Basic educational level might be important, but knowledge resources specific to the industry are not given from outside but are supposed to grow spontaneously by its internal force in the industry structure, once a nation acquired its basic technology.

ii) capital resources, such as availability of low interest rate loans, might be also important. In general, high capital cost may force firms to focus on low capital intensive

*9. Japanese government did some research projects on the topic partially related semiconductors in these periods, but the focus of these research were not semiconductor. Examples are, Opto-electronics Project (1979—85), Supercomputer Project (1981—89), and Fifth Generation Project (1982—91).
products, such as designing intensive products. However this capital resources factor does not always explain the reversal of competitiveness between the US and Japan, as explained later.

In the next chapter I will review what had happened in the competitiveness from the view of macro-economic effect, such as demand increase and changes in its segments, including exchange rate, in order to extract and evaluate these changes of technological level. In chapter 3, the transformation of technological linkages of industry, which will be a force to increase technological level, as well as industry structure will be discussed. In chapter 4, the role played by consortia in this transformation will be discussed.

(2) Human Resources and Basic Technological Level

Although it might be very difficult to assess educational level of nations, there might seem to be no significant differences among these three countries in total. As for basic educational level, Japan and Korea seems to have higher educational level in average. According to the Third International Maths and Science Study, Japan and Korea are third and second position in mathematics and third and fourth position in science respectively, while US is 28th and 17th out of 41 countries. (13 years old average score. The Economist, 1997) On the other hand, the United States, undoubtedly, have world-first-class universities, which have enough capabilities to producing excellent engineers/researchers to the industry, despite the average scores above.

As for basic technological level of designing and manufacturing semiconductors, all three countries, including Korea, had established this fundamental ground by the mid to late 1980’s. There is not doubt that the US and Japan had enough technology of semiconductor at that time. Korea, on the other hand, had little technological knowledge of semiconductor at least in the late 1970’s, but it began their catch-up process from the late 1970’s and the early 1980’s. The strategy of Korean firms to acquire technology may be interesting. Their basic strategy was to import technologies from the United States by ways of human resources and licensing, and then to adopt them. For example, as for the human resource, Samsung hired Korean-American Ph.D.s who had experiences of IBM, Honeywell, Zilog, Intel and National Semiconductor at its R&D outpost in Silicon Valley, while Hyundai employed Korean-American Ph.D.s with semiconductor and
computer experiences from Xerox, System Control, Fairchild, and Ford. (Kim, 1997) As for licensing, all of three Korean firms entered into licensing agreements with foreign firms in the early 1980's to the mid-1980's. Table III-1 shows the sources of these technology. Within these three Korean firms, it was Samsung who adopted the technology most successfully. Its strategy of getting licensing might be summarized as followings; 1) choose small firms who are willing to sell their technology, 2) choose two firms for licensing, 3) gradually decreasing the dependence on licensing. Through this strategy, Samsung was far ahead in semiconductor technology development by mid-1980's compared with other two Korean firms.

Table III-1. Main Licensing Sources of Korean Firms

<table>
<thead>
<tr>
<th></th>
<th>64K</th>
<th>256K</th>
<th>1M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>(P) Micron Tech.</td>
<td>− own−</td>
<td>− own−</td>
</tr>
<tr>
<td></td>
<td>(D) Zytrex</td>
<td>(D) Micron Tech.</td>
<td>− own−</td>
</tr>
<tr>
<td>Hyundai</td>
<td>(OEM) TI</td>
<td>(OEM) TI</td>
<td>(P+D) Vitelic</td>
</tr>
<tr>
<td></td>
<td>(P) → (D) Vitelic</td>
<td>(D) Inmos −&gt; Vitelic</td>
<td></td>
</tr>
<tr>
<td>LG</td>
<td>(JV) AT&amp;T</td>
<td></td>
<td>(OEM) Hitachi</td>
</tr>
<tr>
<td></td>
<td>(D) AMD, Zilog</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(P): process technology, (D): design, (OEM): original equipment manufacture, (JV): joint venture
(Sources) Kim (1997)

Government role in this period might be relatively small and indirect, at least compared with its historical standards of Korean industry policy. However, the firms' decision to enter into this industry might have clearly affected by the government signaling efforts through its five year plans and its demonstration project at Silicon Valley, as well as through significant amount of governmental R&D funding or other financial incentives. (As for the government funding for this period, see Chen et al. (1996))
(3) Capital Resources and R&D Investment

<Capital resources>

Some, especially industry side in the U.S., claims that high cost of capital is one of the main problems of the United States semiconductor industry's competitiveness against Japan. (for example, Howell et al., 1992) This capital factor might be important since semiconductor industry is one of the most capital intensive industry, and learning effect on productivity is high. (Irwin et al., 1994b) Capital market is glowing rapidly towards globalization but still domestic market is important. Comparative advantage may predict that a country with advantage in capital availability tends to focus on capital intensive industries or at least capital intensive products/segments.

However, how does this capital difference matter? First of all, was this capital factor critical to these competitiveness changes? Some suggest the possibility that the collapse of the Japanese bubble economy had limited the availability and increased the cost of capital to Japanese semiconductor firms. (Green, 1996) It might be true that the breakdown of the Japanese bubble economy has depressed products market, and that its clash down of the stock market gave firms a disincentive to invest and a difficulty in financing through stock market. However it seems unlikely that this collapse had been an only determinant in these competitiveness changes, because interest rate in Japan has been the lowest level for record and because electronics and semiconductor industry has not been affected by the bubble economy compared with other industries.

Second, let's consider the case of Korea. Korean industry succeeded in semiconductor industry despite its high interest rate. Usually, interest rate from Korean banks is not low at all. (approximately 12%). Although semiconductor industry can get reduced interest rate for R&D and a limited amount of no interest loan due to government subsidies, most of them are still high (6% to 7%) compared with those of advanced countries. (EIAJ, 1996) Actually, apart from government subsidy, most of the capital sources are within firms. Chaebols, conglomerates with diversified businesses, invested semiconductor industry mainly using their internal profits from other businesses, as well as from foreign loan based on their high credibility in international money market. (Kim, 1997). In this sense, firms' internal structure, rather than its firm-finance structure, mattered to this mobilization of capital.
Table III-2. R&D Expenditure per Sales in Semiconductor Industry

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>Japan</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>70−87</td>
<td>7.5%</td>
<td>14.6%</td>
<td>9.5%</td>
</tr>
<tr>
<td>88−92</td>
<td>10.7%</td>
<td>15.2%</td>
<td></td>
</tr>
<tr>
<td>75−81</td>
<td></td>
<td>15.5%</td>
<td></td>
</tr>
<tr>
<td>82−87</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>88−93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>94</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source) US: Irwin et al. (1994a),
Japan: MITI (cited in EIAJ, IC Guidebook '94),
Korea: EIAJ & SIRII (1996)

<R&D investment>

Now let's consider the effect of this capital factor on R&D investment. The pattern of R&D investment will also affect the competitiveness changes, since semiconductor industry is one of the technology intensive industry as well, which needs high R&D investment level. Table III-2 shows R&D expenditure per sales of three nations' semiconductor industry. Although direct comparison of these numbers might be ambiguous since data sources are different (for example, US data includes a lot of small firms), in general, US industry’s R&D investment is relatively low compared with those of Japanese industry in spite of its gradual increase. One of the main arguments on this low-level R&D investment is often attributed to its difference of financial systems. U.S. industry in general is preoccupied with short time horizon profit as illustrated by quarterly system in stock market, and discouraged to invest in long term strategy such as R&D, while Japanese firms are able to secure stable finance supply through their main bank systems. (Dertouzos et al., 1989)

As for the Korean industry, they have a still relatively low-level of R&D investment, even compared with that of Japanese industry of two decade ago. It needs further examinations to determine how the Korean financial system (including inner profits transfer) plays a role in this investment in R&D, but it seems naturally to think that this fact might suggest that Korean firms are still in a catching up process in terms of research and development at least in some segments. Actually they are still paying a lot on royalty. (Out of this R&D expenditure, 80% are in-house R&D (including abroad), 8% are payments of royalty to foreign firms and 12% are contract or others. Actually Samsung’s R&D expenditure per sales is just about 7%). Also it should be noted that
government R&D spending is also increasing along with private investment increase. (*10)

These firm-finance systems, including government incentives, might affect directly to the technological development. However, it seems to still fail to explain the competitiveness change of industry of both industries, since no dramatic change may have been occurred in this period. At least as long as we see these numbers, Japanese industry seems to have still an advantage over US and Korean industry. Considering that R&D investment per sales is rather decided by firms’ view for the necessity of technological development, this R&D investment per sales might be one of the indicator of rivalry for technological competition rather than that of long term capital availability. In general, as technological rivalry heightens, firms tends to spend more money on research and development to compete with each other. According to some executives in Japanese companies, "There are no definitely right amount on R&D expenditure. We usually decide it by comparing with other rivals’s number, setting it a little bit higher than the rivals, and taking the rivals’ strength into considerations." (author’s interviews, 1994) In this sense, R&D investment may be rather a factor decided mainly by rivalry. If this view is true, the numbers in Table III-2 suggests that the US firms and Korean firms have lower rivalry level than that of Japanese firms. Although further examination must be made for the effect of this firm-finance systems on technological development, financing may not be an only decisive factor of competitiveness changes.

*10. Governmental role in R&D expenditure has still some importance as a complement of this low level of private R&D expenditure and the government continue to spend on R&D constantly. For example, government expenditure on their 40 million, $120 million, and $120 million respectively. (EIAJ & SIRIJ, 1996) In 1992, the government announced that it would invest $1,450 million in semiconductor research and development as a part of their G7 project for next decade (1992 to 2001). (Research-Technology Management, 1992) This includes research fund for governments laboratories and universities. One tenth of this investment (annual average) would be equal to approximately 20% of private companies R&D investment in 1994.
Chapter 2. Revaluation of Technological Strength Changes

(1) Competitiveness and Market Growth Effect through Vertical Linkage

(a) Concept

In this chapter, I will analyse and assess what have happened at the competitiveness of semiconductor industry. The purpose of this chapter is to revaluate the popular idea of the US industry's resurgence, the Japanese industry's decline and the Korean industry's emergence and, and to estimate their real change of technological level.

Generally, people refer the world market share changes as the evidence of those competitiveness changes. However, an industry tends to sell its products on domestic market even in the case of globalized products like semiconductors due to domestic vertical linkages as mentioned before. Therefore the growth of domestic market might be important for its competitiveness as a "world share".

Figure III-1. Annual Percent Change of World Share by Industry and Market (Semiconductor)

(Source) SIA

Figure III-1 shows annual changes of world share of the US industry and Japanese
industry and of world share of the United States market and Japanese market. Clearly, sales of an industry and domestic market are correlated with each other, probably due to the domestic vertical linkage. This linkage between market and firms is not new observation, as Green (1996) put "fundamentally it (Japan) has been surged in domestic market (in the early 1980’s)." However, this fact may arise two further questions as follows. First, how much did the difference of market growth rate between nations/regions affect these world share of industries? In other words, it is important to know to what extent have domestic vertical linkage and vertical linkage with foreign market changed. These changes will reflect "pure" technological effect in a broad sense in these competitiveness changes. Second question is how really each domestic market has grown in terms of local currency. In general, domestic firms recognize domestic market growth by its value at local currency. Therefore there is a possibility that the domestic market growth, which is measured by the amount of sales in dollars, might be exaggerated or under-estimated from standpoint of firms. Especially, the emergence of Japanese industry in the middle of the 1980’s might be too much exaggerated by its exchange rate changes than statics shows, since this is the period when Japanese yen appreciated rapidly against US dollar. (Howell et al. 1988)

Taking these into considerations, I will separate the changes of the world share into three factors; "market growth factor", which comprises two factors of "exchange rate factor" and "pure market growth factor", and "market penetration factor". Market growth factor is a potion of world share increase/decrease of each industry, suppose there were no changes in market sales share in each market (domestic and foreign), thus no changes in vertical linkages of trade. This is the factor which indicates how the difference of market growth affected the world sales share of industries. This is rather a quasi-static effect in terms of its assumption that competitiveness change for vertical trade linkages had not occurred. Out of this factor, pure market growth factor is a potion of market growth factor, suppose there were no changes in the exchange rate, while exchange rate factor is a potion supposed there were no changes in market growth measured by local currency. Market penetration factor, as contrast to market growth factor, is the potion supposed there were no difference in market growth of each market, and shows the changes in its vertical trade linkage. This factor indicates how industries can penetrate into foreign market while securing domestic market. Apart from some international trade
disturbances (*11), this factor is like an indicator of relative increase/ decrease of technological level of industries in a broad term (including its marketing effort in domestic and foreign market), since penetrating into a market needs not only technological level increase in narrow term but also needs its marketing efforts to link with a market in order to overcome the transaction cost. As mentioned at the theoretical part, this factor is supposed to be determined by vertical and horizontal technological linkage of the industry, as well as its industry structure. These factors above are mathematically expressed in Appendix.

These factors are dynamically co-related with each other. For example, as mentioned at the theoretical part, there is a co-development between market (pure market growth factor) and technology (market penetration factor). Market growth may trigger the technology development of domestic firms through the existing vertical technological linkage and enable firms to expand into foreign market, while technological development will stimulate new market growth and expand vertical linkage of trade.

Exchange rate factor and market penetration factor are also co-related with each other, but this relationship is rather ambiguous. On one hand, changes of exchange rate might greatly affect the market penetration factor in a dynamic sense. For example, a domestic industry may lose their competitiveness by way of market penetration factor decrease if the speed of appreciation of local currency is faster than that of productivity increase. However, even in this case, this increasing competition may give firms incentives to develop technology further and to relocate their manufacturing plants to another countries. On the other hand, development of technology may enable nation of the firms’ basis to increase its market penetration factor through increasing export/ decreasing import, which will contribute the appreciation of local currency. However, this effect may be relatively small since semiconductor trade is not majority of international trade and, international trade is not the sole determinant of exchange rate, which tends to fluctuate tremendously by speculation.

*11. One of the example of trade restriction measures is the US-Japan Semiconductor Arrangement in 1986 and 1991. The effect of this arrangement might be considerably large, and is widely reported. (such as Flamm, 1996) Examples are; cartel-like profit of Japanese firms, emergence of Korean firms, and increasing foreign investment by US downstream industry. (Dick, 1995) However, this topic will be beyond the scope of this thesis.
(b) Analysis 1 – Market Growth Factor and Linkage with Downstream Industry

Figure III-2 shows that annual change of world share and the contribution of exchange rate factor, pure market growth factor, and market penetration factor for the US based industry, Japan based industry and other countries’ based industry.

Figure III-2. Annual Percent Changes of World Share by Factors

(Source) SIA (calculated)
(Remarks) see Appendix
In order to round these fluctuated numbers and to understand what really have happened, I divided into two period: 6 years from 1982 to 1988, a period when the US based industry lost its competitiveness and the Japan-based industry gained it, and 6 years from 1988 to 1994 when the US based industry regained it back, the Japan-based industry lost it, and Korean industry emerged. Table III-3 shows the world share changes by three factors mentioned above in these two periods.

Table III-3. World Share Changes before/after 1988 by Factors

<table>
<thead>
<tr>
<th></th>
<th>US based</th>
<th>Japan based</th>
<th>Other based</th>
</tr>
</thead>
<tbody>
<tr>
<td>82–88</td>
<td>−19.4</td>
<td>+18.8</td>
<td>+0.7</td>
</tr>
<tr>
<td>88–94</td>
<td>+6.4</td>
<td>−11.7</td>
<td>+5.3</td>
</tr>
<tr>
<td>total change</td>
<td>−19.4</td>
<td>+18.8</td>
<td>+0.7</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th></th>
<th>US based</th>
<th>Japan based</th>
<th>Other based</th>
</tr>
</thead>
<tbody>
<tr>
<td>exchange rate</td>
<td>−8.2</td>
<td>+8.8</td>
<td>−0.6</td>
</tr>
<tr>
<td>pure market</td>
<td>−2.2</td>
<td>+1.9</td>
<td>+0.3</td>
</tr>
<tr>
<td>penetration</td>
<td>−8.9</td>
<td>−8.0</td>
<td>+1.0</td>
</tr>
</tbody>
</table>

(Source) SIA (calculated)
(Remarks) see Appendix

From Table III-3, three points can be deduced. First, the US decline and Japan’s emergence before 1988 were exaggerated by market growth factor almost by half. More than 40% of the US decrease and Japanese increase can be explained exchange rate changes. Especially for the latter half of 3 years from 1985 to 1988, this exchange rate factor contributes −7.7 points and +6.2 points for the US and Japan based industry respectively, while in the former half of 3 years from 1982 to 1985, pure market growth played a significant role. (−5.6 points for US and +3.8 points for Japan.) However it is also true that the US based industry lost its technological strength (in a broad term) compared with the Japan-based industry, as can be seen from the fact that more than 40% of these changes are due to market penetration factor. One of these changes of technological level might be ascribed to co-development of market and technology, which can be seen from the coincidence of pure market growth factor and market penetration factor. Also these decrease/increase of technological levels of the US/Japan-based industry might affected the rapid changes of exchange rate between two countries.
Second, as for the period from 1988 to 1994, almost all changes in this period can be explained by pure market growth factor (about 95% for US and 80% for Japan). Exchange rate factor rather contributed in an opposite direction; US for decrease while Japan for increase. However, it is also true that market penetration factor played a considerable role. Compensating this exchange rate factor changes, these market penetration factors contributed about 30% and 50% of competitiveness changes of the US and Japan based industry, respectively. As for the relationship between factors, again, co-development between market (pure market growth factor) and technology (exchange rate factor) can be observed, while the relationship with exchange rate factor, this time, is negative. This might suggest that the appreciation of Japanese yen has overrun for Japan based industry to compete with the US based industry.

What is common and striking to both of these two periods is co-development between market and technology; the effect of relative market growth difference to the market penetration factors, and thus to total competitiveness of change between the US and Japan. Then why had these market growth changes occurred? Figure III-3 shows the difference of the GNP growth, the growth of semiconductor market share, and the pure market growth factor between the United States and Japan.

Figure III-3. Difference of Pure Market Factor, Semiconductor Market Growth and Economic Growth between the United States and Japan

(Sources) SIA, OECD
First, all of three lines are synchronized with each other in general. Although extremely sensitive, up and down of difference of semiconductor market share growth is almost same as those of economic growth difference. This high fluctuation of market share growth difference would be soothed by international trade to be the difference of pure market growth factor between two countries. Since semiconductor industry is still occupying only a small portion of economy, it may be possible to say that market growth of semiconductor industry and thus competitiveness of industry are strongly and sensitively affected by its domestic macro-economic situation.

Second, the difference of market share growth and that of pure market growth factor has been larger than that of economic growth since 1986. This means that the US semiconductor market has succeeded to achieve faster growth than that of Japanese market even if the difference of two countries' economic growth is taken into consideration. Although further discussion must be necessary, one thing that can be pointed out as the reason of the rapid growth of US market is the difference between US market structure and that of the Japanese market. As can be seen from Figure III-4, the US market is depending on computer market more than 60%, while Japan is depending on consumer electronics around 40%. It may be possible to be said that the US succeeded to grow computer and information related industry more rapidly than Japan did.

Figure III-4. Semiconductor Market by Application (1993)

(Source) WSTS (cited in Young (1994))

Third point that can be raised from Table III-2 is the emergence of other countries based industry, that is European based industry and Asian based industry. Although
Figure I-1 shows the results mixed with European industry and Asian industry, the most prominently growing industry is the Asian industry, notably Korean industry, as can been seen from Figure III-5. Out of rapid increase of Asian based industry, almost a half of this role is played by Samsung, and almost 85% are by 3 Korean firms (Samsung, Hyundai, and LG) in 1994. (Kim, 1997). As for the case of Korean semiconductor industry, since they exported almost 80% to 90% products to abroad (including foreign owned industries in Korea, Kim, 1997), their emergence of competitiveness little matters with market growth factor but almost only with market penetration factor. This is quite different pattern from that of US industry resurgence.

Figure III-5. World Market Share of Europe Based and Asia Based Industry


(c) Analysis 2 – Market Growth Factor and Linkage with Upstream Industry

These discussions above about market growth factor and competitiveness of industry can be applied to the relationship with upstream industry, which is semiconductor materials and equipment (SME) industry. The increase of domestic semiconductor sales may trigger high investment for its manufacturing factory, then demand for manufacturing equipment may increase through domestic vertical linkage. In this regard, firms in a high domestic growth market may have an advantage because of the same reason above.
Figure III-6 shows the annual changes of the sales in world share of the United States and Japan based semiconductor industry and semiconductor equipment industry. As can be seen, first, the changes (up and down) of both semiconductor sales and equipment sales are, again, almost synchronized and their extents of changes are almost equal. This fact suggests the co-development of industries; that is, market growth factor (including exchange rate factor and pure market growth factor) is still important for the changes of the competitiveness (world share) of equipment industry, as same as that of the relationship with semiconductor sales and its market.

Second, on a closer look, the change of tide has occurred at a little bit different time. The rise of semiconductor industry of the United States is about one or two year ahead to that of equipment industry of the United States. One of the explanations which this fact suggests is that growth of the US based equipment industry is characterized as a market driven share growth rather than investment (thus technology) driven growth; that is, the US semiconductor industry began to increase their investment a year or two later after rapid increase of semiconductor demand because they found that existing facilities were too small to meet the demand, and then the world share of the U.S. equipment industry began to increased through its vertical linkage.

There might be another explanation in this fact, which suggest that technological
linkage was strengthened at that time, probably due to SEMATECH. This explanation may describe that technological linkages was so weakened in this one or two years period that equipment industry could not keep up with the co-development with semiconductor industry. This topic will be discussed in the next section. Whichever the reason is, co-development of market and technology began to work after this period; through vertical technological linkages, technological strength of semiconductor equipment industry grew after triggered by market growth of semiconductor, then contributed to the increase of technological strength and market of semiconductor industry.

How market penetration factor contributed to these changes? Table III-4 shows the equipment market share in the United States and Japan. Although there might be some problems in data accuracy (*12), in general, the market penetration does not changed so much. (*13) Curiously both the US firms and Japanese firms increased their share in their domestic markets although its changes are small. This may suggest that linkage with domestic semiconductor firms was tightened in both countries.

Table III-4. Market Share of US Based and Japan Based Firms in the US and Japanese Market (semiconductor equipment industry)

<table>
<thead>
<tr>
<th></th>
<th>US market</th>
<th>Japanese market</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989</td>
<td>1995</td>
</tr>
<tr>
<td>US based firms</td>
<td>75%</td>
<td>77%</td>
</tr>
<tr>
<td>Japan based firms</td>
<td>22%</td>
<td>15%</td>
</tr>
<tr>
<td>Other firms</td>
<td>3%</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1989</td>
<td>1995</td>
</tr>
<tr>
<td>US based firms</td>
<td>75%</td>
<td>77%</td>
</tr>
<tr>
<td>Japan based firms</td>
<td>22%</td>
<td>15%</td>
</tr>
<tr>
<td>Other firms</td>
<td>3%</td>
<td>8%</td>
</tr>
</tbody>
</table>

(Source) VLSI Research (adapted from USITC (1991) for 1989, and from EIAJ & SIRIJ (1996) for 1995.)

*12. According to the same VLSI Research’s 1987 data that is cited in Howell et al. (1992), US and Japanese firms have about 80% and 16% in US market, and 18% and 80% in Japanese market, respectively. Probably this is because of firms' nationality problems. (such as nationality of JVs)

*13. Exception is Japanese firms in the US market, where Japanese firms lost while other (mostly Europe) based firms won. Apart from yearly fluctuations, this is probably due to European firms' strength in assembly equipment segment especially against US firms, and to US firms overall strength against Japanese firms and European firms. Actually European firms are losing their share in European market. In Japanese market, European firms may not strong enough against Japanese firms to overcome transaction cost. This technological specialization of industries will be examined in the next section.
(2) Competitiveness and Products Specialization

(a) Competitiveness by product segments

In this section, I will review the competitiveness changes of world market share from the viewpoint of the product segments in order to see in which segments each industry got their strengths. Three categories are analysed; MOS memory, MOS micro and others are analysed. Both MOS memory and MOS micro have been regarded as important and rapidly growing segments, especially for its computer use. MOS memory includes DRAM (Dynamic Random Access Memory), SRAM (Static Random Access Memory), ROM (Read Only Memory), EPROM (Erasable Programmable ROM), EEPROM (Electrically Erasable Programmable ROM) and Flash Memory. MOS micro includes micro-processors ("brains" of computer), micro-controllers (including DSP (Digital Signal Processor)) and micro-peripheral.

"Others" segments include MOS logic (such as ASICs (application-specific IC's) and PLDs (programmable logic devices)), digital bipolar, analog devices (most of them are special consumer circuits) and discrete devices (such as diodes, rectifiers, transistors and opto-electronics.) This typology can be shown in Table III-5.

Table III-5. Typology of Semiconductor

<table>
<thead>
<tr>
<th>Discrete device</th>
<th>diodes, rectifiers, transistors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>opto-electronics</td>
</tr>
<tr>
<td>Integrated Circuits</td>
<td></td>
</tr>
<tr>
<td>Analog</td>
<td>special consumer circuits</td>
</tr>
<tr>
<td>Digital MOS memory</td>
<td>volatile – DRAM, SRAM</td>
</tr>
<tr>
<td></td>
<td>non-volatile – ROM, EPROM, EEPROM, Flash memory</td>
</tr>
<tr>
<td>MOS micro</td>
<td>micro-processors, micro-controllers, micro-peripheral</td>
</tr>
<tr>
<td>MOS logic</td>
<td>ASICs (gate-arrays, standards cells)</td>
</tr>
<tr>
<td></td>
<td>PLD</td>
</tr>
</tbody>
</table>

- Figure III-7 shows sales share of each segment produced by the US, Japan, Europe and
Asia-based industries out of total world market share.

Figure III-7. World Share of US, Japan, Europe, and Asia Based Industry by Segments (semiconductor)

(Source) Dataquest (adopted from EIAJ (1994) and calculated)

From these figures, two prominent changes can be observed. One is the significant increase of MOS micro production by the United States based industry. The other is the rapidly growing dependence on MOS memory of Asia based industry, notably Korean industry. To what extents have these changes affected the competitiveness changes of semiconductor industries? Table III-6 shows the competitiveness changes before/after 1988 by MOS micro, MOS memory and others segments.
Table III-6. World Share Changes before/after 1988 by Segments (semiconductor)

(82–88 (6 years) TOTAL US based Japan based Europe based Asia based

<table>
<thead>
<tr>
<th></th>
<th>82–88 (6 years)</th>
<th>US based</th>
<th>Japan based</th>
<th>Europe based</th>
<th>Asia based</th>
</tr>
</thead>
<tbody>
<tr>
<td>total changes</td>
<td>0</td>
<td>-14.9</td>
<td>+15.7</td>
<td>-2.9</td>
<td>+2.2</td>
</tr>
<tr>
<td>MOS micro</td>
<td>+5.4</td>
<td>+2.4</td>
<td>+2.4</td>
<td>+0.5</td>
<td>+0.1</td>
</tr>
<tr>
<td>MOS memory</td>
<td>+5.3</td>
<td>-4.6</td>
<td>+8.0</td>
<td>+0.3</td>
<td>+1.5</td>
</tr>
<tr>
<td>others</td>
<td>-10.7</td>
<td>-12.7</td>
<td>+5.2</td>
<td>-3.6</td>
<td>+0.6</td>
</tr>
</tbody>
</table>

(88–92 (4 years) TOTAL US based Japan based Europe based Asia based

<table>
<thead>
<tr>
<th></th>
<th>88–92 (4 years)</th>
<th>US based</th>
<th>Japan based</th>
<th>Europe based</th>
<th>Asia based</th>
</tr>
</thead>
<tbody>
<tr>
<td>total changes</td>
<td>0</td>
<td>+5.1</td>
<td>-9.2</td>
<td>+0.5</td>
<td>+3.5</td>
</tr>
<tr>
<td>MOS micro</td>
<td>+8.0</td>
<td>+7.5</td>
<td>+0.1</td>
<td>+0.2</td>
<td>+0.2</td>
</tr>
<tr>
<td>MOS memory</td>
<td>+0.5</td>
<td>-0.1</td>
<td>-2.7</td>
<td>+0.2</td>
<td>+3.0</td>
</tr>
<tr>
<td>others</td>
<td>-8.4</td>
<td>-2.3</td>
<td>-6.5</td>
<td>+0.1</td>
<td>+0.3</td>
</tr>
</tbody>
</table>

(Source) Dataquest (adopted from EIAJ (1994) and calculated)

From the segment points of view, first, both MOS micro and MOS memory increased about 5 points in the world share before 1988, but in four years from 1988 to 1992 MOS micro increased 8 points while MOS memory increased only 0.5 points (although MOS memory increased its share rapidly again after 1992.) To what extent did these changes affect to each industry’s competitiveness? In order to understand this change, it is necessary to examine closely what have happened in each market.

(b) The United States industry and MOS micro market

Comparing the US industry and Japanese industry, it is clear that MOS micro is the segment that the United States industry gain the competitiveness. Out of 5.1 points increase of the US industry between 1988 and 1992, more than 7 points increase is due to this MOS micro segments increase, which occupies almost all increase of this MOS micro segment in the world (+8.0 points). Japanese industry in this period gains only 0.1 points increase in this segment. This is a quite contrast to the period between 1982 and
1988, when the U.S industry and Japanese industry shared the potion of increase of this segment by almost half (+2.4 points and +2.4 points each out of +5.4 points), although these numbers might be exaggerated by exchange rate factor.

In this competitiveness gain of the US industry in the MOS micro segment, Intel, the No.1 world semiconductor firm, is famous for its come back. To what extent Intel played important role? Intel have shifted their production focus from DRAM (a part of MOS memory) to microprocessors (a part of MOS micro) in the mid 1980's, following the severe competition in DRAM market with Japanese competitors. From that time, their sales of their products increased rapidly, and nowadays Intel has more than 90% share in the PC processor market. (Economist, 1996) This Intel's resurgence is significant.

Figure III-8 shows the changes in the world share of top three US companies (Intel, Motorola, and Texas Instruments) and top three Japanese companies (NEC, Toshiba, and Hitachi) and Samsung between 1987 and 1994.

Figure III-8. World Share Changes of Seven Large Semiconductor Firms

Clearly seen that Intel is the only winner in these six US and Japanese firms. Intel's sales has increased by almost 4 points from 1988 to 1992 and 5 points to 1994. This is a significant potion compared with 5.1 points increase of US industry's world share from 1988 to 1992 (Table III-6) and 6.4 points increase to 1994 (Table III-3). Contrary to this Intel's emergence, other two US companies' share is rather stable.
Motorola and Texas Instruments' share in the world sales is moving around 6.5% and 5.0% respectively. In this sense, it is possible to say that the United States industry's resurgence is mostly due to that of Intel. This fact suggests that it is Intel that won in the semiconductor competitiveness especially in MOS micro segment, and that the other United States' industry role in this competitiveness change is minimum. The Japanese industry, as can be seen that all of the top three Japanese semiconductor firms, NEC, Toshiba, and Hitachi, are decreasing its share in the world sales gradually about one to two points each in this periods.

(c) US, Japan and Korea in memory market and other segment market

Then, let's look at memory market and "others" segment. The changes in the MOS memory and others segments of US industry is still negative to its world share increase. However in general it may be possible to say that the decline of the US industry in these segments had stopped or slowed down. As for the share of MOS memory, the US industry's gain in this period is -0.5 points compared with 0.5 points total increase of this segment. This might be a quite improvement from the previous period, when they decrease 4.6 points despite 5.4 points total market segment increase. Same is true to "others" sector, where the US industry decrease 2.3 points out of 8.4 points decrease of the segments, which is still a quite improvement from the previous period, when the US industry decrease 12.7 points out of 10.7 points decrease of the segment in total. Although it may be necessary to take the market growth factor (pure and exchange rate) into consideration, it might be said that the competitiveness of the US in these segments have been at least stabilized in general.

On the other hand, it is clear that Japanese industry lost its competitiveness in these segments, especially in MOS memory market. Japanese industry in this periods lost 2.7 points in MOS memory segment despite 0.5 points increase in total. This is a quite contrast to the previous period when Japanese industries gained 8 points increase out of 5.3 points increase of the segments, although this might be exaggerated by exchange rate factor.

Then, who won in this competition? It is Korean industry who played a major role in this segment. Out of 3.5 points increase of Asian based industries in total world sales, 3 points are due to the increase in MOS memory, which substitutes the 2.7 points loss of
Japanese industries. Especially, the emergence of Samsung is outstanding. As can be seen in Figure III-8, Samsung's world share increased more than 3 points during the period between 1987 and 1994.

Japan’s decline in "others" segments is also substantial. Out of 8.4 points decrease in this segment, they lost 6.5 points, which makes up about 70% of the reason of Japanese decline during this period. This is also quite in contrast to the previous period when the US’ s industry lost more than its market size decrease. Asian industry also gained share in this segment despite its total market share decrease.

Why have these changes happened? Of course, one of the reason might be the exaggeration by the exchange rate factor in the period of 1982 to 1988 (especially 1985 to 1988) as mentioned before, but the other important reason may be a turn of growth of consumer electronics industry. Since Japanese semiconductor industry is heavily depending on its domestic consumer industry, who is the substantial buyers of this "others" segment, the decrease of its relative demand level would affect the Japanese competitiveness in this segment significantly as compared with the US industry, whose buyers are mostly computer industry, and with the industry based on Asia, where the production of consumer electronics is increasing rapidly.

(d) Competitiveness of SME industry and product segments

Product specialization can be observed also in the SME industry. SME industry is composed of four major segments, of which three are equipment portions; wafer fabrication equipment, test equipment, and assembly and packaging equipment, and processing and packaging materials. Table III-7 shows main segments of semiconductor equipment.
Table III-7. Main Typology of Semiconductor Equipment Industry

<table>
<thead>
<tr>
<th>Wafer fabrication equipment</th>
<th>Test equipment</th>
<th>Assembly and Packaging equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>- lithography (photoresist processing, wafer exposure (stepper), mask-making)</td>
<td>- automatic test equipment (ATE)</td>
<td>- material handling equipment, process monitoring, wafer inspection, etc.</td>
</tr>
<tr>
<td>- diffusion furnaces</td>
<td>- wafer measuring &amp; inspection equipment</td>
<td></td>
</tr>
<tr>
<td>- ion implantation</td>
<td>- others (material handling equipment, process monitoring, wafer inspection, etc.)</td>
<td></td>
</tr>
<tr>
<td>- deposition/diffusion (chemical/physical vapor deposition)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- etching and cleaning</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To what extent did these segments' competitiveness changes affect the total competitiveness changes of semiconductor equipment industries? Table III-8 below shows the difference of world share changes by equipment segments and by industries.

Table III-8. World Share Changes between 1989 and 1994 by Segments (equipment)

( unit: point (changes in percentage))

<table>
<thead>
<tr>
<th>89-94 (5 years)</th>
<th>TOTAL</th>
<th>US based</th>
<th>Japan based</th>
<th>other based</th>
</tr>
</thead>
<tbody>
<tr>
<td>total changes</td>
<td>0</td>
<td>+2.3</td>
<td>-1.0</td>
<td>-1.3</td>
</tr>
<tr>
<td>Lithography</td>
<td>-0.8</td>
<td>-1.8</td>
<td>+1.0</td>
<td>+0.1</td>
</tr>
<tr>
<td>Furnaces</td>
<td>+2.0</td>
<td>-0.0</td>
<td>+1.7</td>
<td>+0.2</td>
</tr>
<tr>
<td>Ion Implantation</td>
<td>-1.8</td>
<td>-0.6</td>
<td>-1.2</td>
<td>-0.0</td>
</tr>
<tr>
<td>Deposition</td>
<td>+2.2</td>
<td>+3.0</td>
<td>+0.4</td>
<td>-1.3</td>
</tr>
<tr>
<td>Etching &amp; Cleaning</td>
<td>+5.5</td>
<td>+2.1</td>
<td>+2.5</td>
<td>+0.9</td>
</tr>
<tr>
<td>ATE</td>
<td>-1.6</td>
<td>+0.8</td>
<td>-1.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>Wafer Measuring</td>
<td>+0.5</td>
<td>+0.5</td>
<td>-1.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>Assembly</td>
<td>-1.6</td>
<td>-1.0</td>
<td>-1.0</td>
<td>+0.4</td>
</tr>
<tr>
<td>others</td>
<td>-4.4</td>
<td>-0.6</td>
<td>-3.0</td>
<td>-0.8</td>
</tr>
</tbody>
</table>

(Source) VLSI Research (adapted from USITC (1991) for 1989 data, and from EIAJ & SIRIJ (1996) for 1995 data, and then calculated.)

(Remark 1) "others" includes equipment service and spare, and other test equipment.
(Remark 2) "" is the strengthening segments.
From the segment points of view, the US’s equipment industry is strengthening its position in wider range of equipment products than that of Japan in general, but more strikingly, the progress of specialization in this industry is apparent. The US industry is gaining its strength in deposition equipment and most of test equipment including ATE, wafer measuring and inspection equipment and probably other process diagnosis equipment, while Japanese industry’s gaining strengths are mostly focused on a part of wafer fabrication equipment, such as lithography equipment, furnace equipment, and to some extent etching and cleaning equipment. Although domestic market growth effect may play a part in this US equipment industry’s wide growth, it is also true that US industry has gained its strength in some process related equipment, such as deposition equipment and test equipment, in which Japanese industry had been considered to be strong. Probably co-development process of market and technology played in a part. As for software related equipment, US industry has overwhelming advantage, although the absolute amount is relatively small. For example, US firms have more than 70% world share in CIM software and test equipment for logic and mixed signal semiconductor, 80% in mask-making equipment (a part of lithography), and almost 100% in process monitoring equipment, which needs database.

On the other hand, Japanese firms still have a stronghold in some wafer fabrication equipment. Especially they have a strong lithography equipment industry (about 80% world share for stepper), mainly because of, again, co-development of market and technology; high level of lithography technology is mostly necessary for manufacturing high miniaturization of semiconductors, and thus for cutting edge DRAM development, in which Japanese semiconductor firms are strong.

As for the "other" nations (mostly European) based industry, it is gaining assembly equipment is gaining advantage. This strength may be partly a result of its JESSI projects. (EIAJ & SIRIJ, 1996)

(3) Summary of the Chapter

As we have seen before, the market changes have significant role in the competitiveness changes in the semiconductor industry. From these analysis, it can be concluded as followings.
(i) The United States semiconductor industry’s resurgence, as well as that of SME industry, in the late 1980’s and the early 1990’s can almost be attributed to the (pure) market growth effect, which was enhanced by its economic growth, while its decline before this period was exaggerated almost half by exchange rate factor. However, there were also co-development process between growing market and technological development, as can be seen the co-relationship with market penetration factor. This may be a main mechanism of technological growth of the US industry, which rebounded from it’s decline before 1988.

(ii) Out of this regain of the US industry, the MOS micro segments played almost of all. In this regard, the role of Intel’s emergence is outstanding, but even excluding Intel, the strength of United States industry became at least almost equal to that of Japanese industry and overall speed of changes has stopped. Relatively speaking, through co-development process of market and technology, US industry increase their technological level on computer related and non-memory products with background of its computer industry and broad range of strong (and especially software related) equipment industry, while the Japanese industry still keeps its technological level on consumer related and memory products with its background of consumer electronics industry and high level of lithography industry.

(iii) The emergence of Asian industry, notably Korean industry, is not related with this vertical linkages; neither with domestic market nor with domestic equipment industry, in contrast to the US growth pattern. It focused on MOS memory products, in which almost of all Japanese decline in this segment can be attributed to the loss over Korean industry’s technological development.
Chapter 3. Causes of Changes – Technological Linkage of Industry

(1) The Source of Technological Strength – Technological Linkage of Industry

In this chapter, the source of these technological strengths of the US industry and Korean industry will be examined. As discussed at theoretical chapters, this paper presumes that the force for technological development, or the sources of technology, will mostly lies in its industry structure, especially as a form of vertical and horizontal technological linkages. Therefore I assumes there must be some changes in these linkages. Based on this belief, I will analyse what has changed these industries’ technological strengths from the viewpoint of its vertical and horizontal technological linkages of the US and Korean industries. Although its basic technological linkages, which links governmental and universities research and development, might be also important for its long term technological development, this paper will discuss this only briefly, since the focus of this paper is rather short-mid term commercial technologies, which are mostly created by industries by themselves.

Basic question asked at this chapter is how technological development was attained in these countries in terms of their technological linkages, both in vertical and horizontal structure. In other words, the question is what was the development pattern of the industry in terms of its industrial structure and technological linkages.

There will be three aspects to see its development pattern in regard to these technological linkages, both in vertical and horizontal structure. First aspect is the relationship between technological linkages and its industry structure. Since technological linkage discussed here is the linkages that connects between firms, the development pattern of industry will also depends on the nature of firms who is the player of industry and who will be connected by these technological linkages, as well as on its linkage itself. In this regard, the strength and its segment of both downstream (market) and upstream (SME) industries will be discussed as for its vertical structure, while the structure of domestic rivalry that includes size, number, and nature of firms will be analysed as for its horizontal structure. As discussed at the theoretical part, the analysis will mainly focus on domestic firms, who are supposed to be connected more
closely with the industry both in terms of non-proprietary information and of proprietary
technology.

Second aspect of the analysis is the transformation of technological linkages both in
terms of non-proprietary information and proprietary technology. This topic may relate
mostly with the topic which was discussed at the theoretical part. As for the vertical
linkages, for example, its marketing effort (including marketing office abroad) and
technological cooperation with SME will be discussed, while as for its horizontal linkages,
information exchange of non-proprietary information among rivals both in terms of direct
exchange and indirect diffusion mechanism will be discussed. Horizontal technology
alliance for proprietary technology exchange might be important but will not be focused
much.

Third aspect is the forces which have transformed these technological linkages. In
other words, what was the background to change this technological linkages? There may
be two forces to change these linkages as an institutions. One is the market or internal
force, which makes firms to changes linkages. This force includes, domestic market
changes, increasing competition with foreign firms and technological changes. The other
is the governmental force, that is its technology policy especially through establishing
consortia.

(2) US Industry Structure and its Technological Linkages Changes

(a) Background of technological linkages changes

In the late 1980's, the US semiconductor industry was in pessimistic mood because
the Japanese "triumphal" competition, the effect of which has been "ruinous". Because of
this severe competition with Japanese industry, it was predicted that "without some
dramatic realignment of the American merchant industry, its decline is likely not only to
continue but to accelerate." (Dertouzos et al., 1989). This kind of perception caused by
competition might be strong enough for them to move toward the spontaneous
reformation of industrial structure as well as to appeal to change the attitude government,
which published numerous documents on this subject during this period. This is in line
with Angel's argument, in which he argues that the initial US response is to "redeploy
their resources away from DRAMs and other commodities devices (where Japan was essentially dominant) and into more design-intensive product markets, such as micro-processors, mixed signal devices, and very fast logic devices", and to seek "a political solution to the competitive challenge by claiming that Japanese firms should be penalized for unfair trading practices." (Angel, 1994)

Another thing that must not be missed in the structural changes of the industry is the market shift in the world from consumer electronics to rapidly growing computer related industry, especially in the United States. This demand-pull was also important in this regard, as mentioned at the last chapter.

The question is how these environmental changes affected the structure of the industry and technological linkages of industry.

(b) Vertical industry structure and its linkages

<Industry Structure – the Relationship with Downstream Industry>

The strong growth of computer-related industry in the United States, as well as severe competition with Japanese industry, might be persuasive enough to explain the changes of technological development of industries through its co-development process. The increasing demand for computer-related products helped to upgrade the technologies of US semiconductor industry’s of this area by giving them a domestic advantage through imperfect information across borders, while the shift to more design-intensive products in the semiconductor industry will facilitate the technological development of this area, triggering the growth of computer- and information related industry. Because of this co-development process, the United States industry was in a good position to upgrade technology and market synergistically, as compared with the Japanese industry, who were depending on its consumer electronics industry.

Intel’s resurgence in this period was a typical example which can be explained in this context. As mentioned before, Intel was the inventor of DRAM, but because of severe competition with Japanese industry in this segments, it has shifted its products to micro-processor, which were perceived as more profitable, and nowadays it attains the No1. place in the world. This situation can explain why the techno-poly in these area has arisen in the United States. Its rapid growth may also be a typical example of techno-poly, which mechanism was explained at the theoretical part. Although this mechanism
of techno-poly might be related with its protection by IPR, its protection of proprietary technology is always perfect, at least in terms of catching up by rivals. Recently it is reported that some compatible chips are recently emerging in the market with quite lower prices, which suggests that Intel has been successful to get a techno-monopolistic profit for a long time. (*14)

<Technological Linkages with Downstream Industries>

This co-development effect of growing market of computer-related industry gives an advantage for the US industry to create technology and to develop into a techno-poly by *de facto* standard because of its domestic technological linkages of non-proprietary information, which played a role as a barrier to Japanese firms in a form of transaction cost.

Besides usual linkages, these two forces (market growth and competition with Japanese firms) pressed US firms to make efforts on strengthening this domestic technological linkage between market and firms, as Angel (1994) put it "the increasing "Japanization" of U.S. manufacturing systems — involving, in particular, much closer cooperative ties among customers, semiconductor producers, and equipment suppliers." Responding to the rapid growth of market and technology especially of design-intensive products, the US firms tried to reduce time for marketing of new technologies as well as to achieve the efficiency of the circuit design process. In this regard, Angel find that the most significant progress can be seen in the final phase of production and yield enhancement rather than in efficient design process. He says "learning from their Japanese competitors, U.S. semiconductor firms moved rapidly during the mid-1980's to integrate the various stages of the technology-development cycle." (Angel, 1994) He explains how the U.S. major firms, such as IBM, Intel and Texas Instruments, built "development facilities", adopted concurrent engineering methods, and created "multi-dimensional technology-development teams that includes personnel from internal research, product development, production, and marketing operations, as well as from external equipment and materials suppliers." This development facilities contributed to

*14. The discussion on whether this profit is an appropriate reward for its technological development or not is another.
create close linkages with market by its geographical proximity of marketing, production and R&D activities – for producing new products, US firms began to built their plants in the US, instead in other countries (especially in developing countries). These facts indicate that under these forces, US firms self-engineered to strengthen their technological linkages with market, especially by reforming its internal structure or adopting practice of Japanese management technology.

The US firms efforts to strengthen the linkage with market are not limited to domestic market but also include foreign market. For example, the number of design center of foreign firms in Japan (mostly of US firms) increased double from 1987 to 1991 (6 to 13), and the number of design-in activities, in which Japanese semiconductor users and foreign semiconductor suppliers work together to specific LSIs, increased rapidly from 100 in 1986 to 698 in 1993. (EIAJ, 1995) These activities were promoted by the User’s Committee of Foreign Semiconductors (UCOM) of two countries’ trade associations (the Electronics Industries Association of Japan (EIAJ) and the U.S. Semiconductor Industry Association (SIA)), which was partly the result of the U.S.—Japan semiconductor trade conflict. Through strengthening the technological linkage with Japanese buyers, these activities may had some but a limited roles in recent surge for US export to Japan, which increased from around 15% share in Japan in 1991 to around 23% share in 1994.

<Industry Structure – the Relationship with Upstream Industry (SMEs)>

This discussion of co-development process is true to the relationship with its upstream industry. As explained at the last chapter, the market increase of domestic semiconductor industry leads to the increase of equipment investment and thus to the increase of sales of SME industry as well as the increase of its technological level through technology linkages. Also its technological level increase may have contributed to the growth of semiconductor industry. In this sense, the existence of strong SME industries is important for semiconductor firms to attain this co-develop process of technology, and in general both US and Japan have SME industries with almost even strength.

The effect of this co-development process on the competitiveness changes can be understand from its segment analysis as well as in general view. In general view, the US equipment firms strengthened its technological level in a broad range of segments of
equipment, which includes not only some test equipment but also some wafer fabrication equipment. VLSI Research Inc. indicated that "underlining strengths suggest it will last beyond the Japanese slow down." (Green, 1996), while Japanese sides also recently raised the concern for the effect of technological advancement of the United States SME industry to Japanese competitiveness. (EIAJ & SIRIJ, 1996) This co-development process is clearer from segments point of view, which shows a different view of the competitiveness of US and Japanese firms. For example, the existence of strong software related equipment industry in the US contributed the technological strength of design intensive products, which US semiconductor industry focuses, while strong lithography equipment manufacturers gives an advantage to Japanese semiconductor industry, who is focusing on DRAM development and who desperately needs new cutting edge technology of lithography for its miniaturization.

<Technological Linkages with Upstream Industries (SMEs)>

This technological development of equipment industry through its co-development process has been partly achieved by closer technological linkage with semiconductor industry than before. First of all, as for the effort of each firm, the argument about adoption of Japanese practice by the US firms ("Japanization") may be also true to the relationship with equipment suppliers to some extent. From the view of industry structure, US SME industry was distinct from that of Japan in terms of its size, as Green (1996) says, "the industry network of American SM&E firms is highly fragmented, dominated by hundreds of small firms, most of which have annual sales of less than $20 million. As a result, the American SM&E industry suffers several structural disadvantages compared to its larger Japanese counterparts." Partly due to this difference, many analysts have criticized the US industry for not to take a risk and cost of new technology of equipment but to beat the price down through competition. (Angel, 1994) This might be a prisoners' dilemma described at the theoretical part, in which players tend to choose non-cooperation, cut prices down, and free-ride others efforts because single cooperation will not pay off for a player. In this regard, Angel (1994) found that, according to his survey, there are some improvement to have a closer relationship with equipment suppliers compared with the one conducted by General Accounting Office (1990) a few years earlier, although he commented that firms with close linkage is still a minority.
SEMATECH played an important role in this regard as a compensation of this relatively small progress of creating linkage with equipment suppliers. SEMATECH's main strategy was actually to create this linkage with equipment suppliers, as Green put "An important contribution of SEMATECH has been to foster closer working relations between SM&E suppliers and semiconductor producers." (Green, 1996) I will discuss the role of SEMATECH further in the next chapter.

This close technological linkage created by SEMATECH have certainly affected their domestic trade linkage. For instance, following SEMATECH initiatives, National Semiconductor and Intel purchased largely American-made equipment and Motorola, who had used only 25% domestic made equipment before SEMATECH established, also began to employ 80% domestic equipment by 1991. (Green, 1996). This close linkages created by SEMATECH might be one of the reason which can explain the one or two year delay of competitive increase of US equipment firms. If this is true, SEMATECH's role in its SME industry's surge might be appreciated. On the other hand, it might be ironic that the US government helped US firms to create vertical structure like keiretsu, which US government has criticized against Japan for long as inflexible and inefficient.

However, SEMATECH was not always successful in all segments of the SME industries which it tried to reinforce. Opponents of the US industry policy often suggest the failure of SEMATECH's effort in lithography, which was a crucial area in its effort. SEMATECH invested in GCA and Silicon Valley Group Lithography (SVGL), two main US lithography manufacturer in the United States, about $60 million and $30 million respectively. Both of firms have succeeded in developing world first class technology, but mainly due to lack of management capability and its bad reputation about financial capability from buyers, GCA was forced to be sold out and SVGL had technology-development partnership with Canon, a Japanese competitor. (Young, 1994) This may suggest some technology development are not only a matter of R&D funds but also a matter of total healthiness of firms, probably which can be fostered by a favorable industry structure, such as rival firms or strong buyers, as a surrounding environment.

(c) Horizontal industry structure and its linkages

<Horizontal industry structure>

There are a striking difference in the horizontal structure (ex. number and size)
between semiconductor firms in the United States and those of Japan. Contrast to Japanese industry, which are concentrating in a quite number of big firms, the US industry holds several big firms with numerous small firms. Table III-9 shows this difference.

Table III-9. Number and Size of Semiconductor Firms

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>$1 billion —</td>
<td>6</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>$200 million — $1 billion</td>
<td>12</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>— $200 million</td>
<td>more than 100</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
</tbody>
</table>

(Firms with more than $1 billion sales)
- US: Intel, Motorola, Texas Instruments, National Semiconductor, Advanced Micro Devices, IBM(captive)
- Japan: NEC, Toshiba, Hitachi, Fujitsu, Mitsubishi, Matsushita, Sanyo, Sharp, Sony, Oki, Rohm
- Korea: Samsung, LG, Hyundai

(Source) US: Angel (1994)
Korea: Kim (1997)

(Remark 1) Out of top 18 US firms, 5 firms are captive (not selling to outside).
(Remark 2) According to Porter (1990), there are 34 and 21 semiconductor firms in Japan and Korea respectively in 1987 and 1988, including foreign owned firms. Although the data of these firms are not available, most of Japanese small and middle firms are still a part of big business (such as Yamaha, Seiko Epson, and Ricoh), and a subsidiary of diversified business with foreign firms (for example, several steel firms such as Nippon Steel, Kobe Steel, Kawasaki Steel and NKK). As for Korean firms, there are eight domestic firms, which include Daewoo and Korean Semiconductor, out of 21 firms.

The other difference is that US big firms are specialized in semiconductor industry, while the Japanese and Korean industry is doing semiconductor business as a part of the extent of their large business. For example, most of the US big firms have more than 70% of semiconductor share within total sales (except Motorola (31%) and TI (36%)), while most of Japanese big firms have less than 10% share (except NEC (18%)). (Hobday, 1989) Moreover, these relatively diversified US firms have a different business (for example, Motorola is based on telecommunication products, while TI is based on electronics/ calculator-related products), while Japanese firms are relatively homogeneous in terms of their main business. Japanese top 10 firms can be divided into three category: 1) computer and communication companies (NEC, Fujitsu, Oki), 2) general
electronics companies (Toshiba, Hitachi, Mitsubishi), and 3) consumer electronics companies (Matsushita, Sanyo, Sharp, Sony) (Wakasugi, 1986), but in sum, all of them are electronic-related firms and most of their diversified business are competing with each other. For example, they all are manufacturers of, say, computers.

Two implications can be deduced from these differences. First, the rivalry among US firms in the high volume VLSI segment, such as DRAM (and micro-processor), is less severe than that of Japanese firms. This is because US has relatively small number and differentiated big firms, which are supposed to be able to produce high volume VLSI (in general smaller firms are unable to burden large cost and risks), while the number of Japanese big firms are large and their strategy on products tends to be similar due to their homogeneous main businesses. Therefore this may be a disadvantage for US firms in general in these segments, since domestic rivalry is the main source of technological development.

Second, the existence of small semiconductor firms (not part of big businesses) in the United States will be an advantage for US firms to create differentiated and new products. In general, smaller firms tend to pursue specialized or niche market for customized products in order to avoid direct conflict with big firms, since they are not able to compete with big firms. Even in Japan, for example, Rohm, its 11th largest firm, which is, unlike other big Japanese firms, depending three fourth of its sales on semiconductor has quite a different strategy from those of other ten big firms. (Enomoto, 1995) This strategy of small firms tend to create new technologies through their more design technology intensive strategy (software or "idea" intensive) rather than manufacturing technology and capital intensive strategy, which big firms have an advantage. Therefore the existence of these small firms will be an advantage for US big firms not only by stimulating the technological rivalry but also by serving as a source of new and diversified technology for the industry.

<Technological linkage>

The nature of horizontal technological linkages between firms is heavily depending on these horizontal structures. In general, horizontal technological linkage of the US industry, especially of those small firms, is based on direct information exchanges between engineers and researchers, which are made not only at formal opportunities like conversation at academic societies' conference but also at informal opportunities, and
through personnel exchange through job changes.

A typical example is its Silicon Valley — a capital of semiconductor, where a large number of small semiconductor firms congregate (approximately 30% of total facilities) and compete with each other to develop new products for new market. In this region, daily communication among engineers and researchers of different firms is frequent. As many analysts say, even restaurants and pubs are the places to exchange technological information (though not always proprietary technology) in Silicon Valley (Saxenian, 1994) Angels (1994) commented that "the US (start-up) semiconductor industry is characterized by an open technology-environment in which technological knowledge flows relatively rapidly from one firm to another." Although there are many discussion about this mechanism of Silicon Valley, one of the reason of this emergence of strong technological linkages (sometimes including proprietary technology) may be their success on creating cooperation in prisoners' dilemma situation due to the fact that these small firms are not always rivals each other but depending technologies with each other.

The characteristics of these strong technological linkages through direct information exchanges in Silicon Valley may be somewhat true even to US big firms but not always the case. Some of the big firms, such as Intel, AMD, and National Semiconductor, have headquarters in Silicon Valley, thus they may be a good position to contact with these small firms. Indeed many firms around the world try to connect with this Silicon Valley area, and sometimes try to buy some firms, but the frequency of contact may be different from that of these three firms. Job changes of engineers and researchers are also frequent among US electronics firms as some estimate that this can be up to 20%. (Ferguson, 1987) This geography proximity and frequent job changes may be at least enough to give clear idea on counterpart firms’ technological activities and their strategy, and sometimes these information exchanges might include proprietary technology, since direct information exchange is deeper linkage which can involve proprietary technology. However, these characteristics might be a little bit exaggerated for some US firms outside Silicon Valley since, for example, job changes are not so common in firms like IBM, Motorola and TI, which have relatively similar firm structures with that of Japanese firms.

This characteristic of technological linkages based on direct information exchange is quite contrast with big Japanese firms, in which rivalry among firms are so strong and life time employment system are implicitly adopted so that few employees change their jobs
to other firms including its rivals. Instead, Japanese firms tends to depend on indirect information exchanges/ diffusion, which are through some media (such as magazines) or vertical relationship. In general terms, Porter (1990) remarks,

Another important area of factor creation in Japan, and some ways the most critical, is the area of information. Every Japanese company and Japanese citizenship is inundated with economic information. Data are available in profusion in Japan (about market share, company developments, technical trends, and so on) in those industries and product areas in which Japan has a position. Information is made available by the media, government agencies, industry associations, and countless other organization, which crank out report after report and book after book. This pool of economic information, unrivaled even in the United States, is an important part of process of rivalry among Japanese companies.

He also suggested that their bias on market share ranking rather than financial ranking might be a sources of Japanese firms' general tendency to pursue market share. In this sense, information exchange/ diffusion mechanism in Japan is sustained without damaging rivalry, not by voluntary mutual trust, which can be seen Silicon Valley, but by institutions of third parties. (ex. media etc.)

Of course, there are some similarities in these indirect information linkages between Japanese big firms and US big firms. For example, as for media, both of countries have industry specific magazines or newspapers, such as "Electronics" and "Electronic Business" in the US and "Nikkei Microdevice" in Japan, whose reporters visit each firm and try to collect sensitive issues such as technological trends, specification, and production plan of the firms, and then publish in comparisons with other firms. As for trade associations, both of them have active associations, such as Semiconductor Industry Association (SIA) in the US and Electronics Industry Association of Japan (EIAJ) in Japan. Even as for direct technological information exchanges, substantial number of engineers/ researchers of both of industries attend at conferences of academic societies, such as International Solid State Circuit Conference (ISSCC) and International Electronic Device Meeting (IEDC) and (possibly) make formal and informal conversations with rival firms' engineers/ researchers.

However, another important channel of indirect technological information
exchanges/diffusion is through its vertical linkage, which Japanese firms have an advantage. Vertical linkage, either through market or suppliers, can be an important source of information. A Japanese engineer comments that during conversation with equipment suppliers, suppliers will indicate implicitly what the rivals firms are doing, although they never leak rivals information explicitly. (Yoneyama et al, 1995)

SEMATECH also played some roles in this regard. Close vertical linkage can be another path of indirect information exchange/diffusion. Moreover, their road map making process might also played a role as another trade association for engineers. The joint laboratory at Austin, Texas might be another place of Silicon Valley for big firms, although they may not exchange their proprietary technology as small firms. In fact some executives commented that SEMATECH was useful in terms of information exchanges. I will discussed this role in detail later.

How does this contrast between US and Japan in the nature of horizontal technological linkages affect their technological development? US big firms, which are depending on rather direct information exchange, will be able to acquire, at least, a clearer view of rival’s technological progress or its level, and sometimes information which is near to rivals proprietary technology. This kind of information may not always be enough to acquire all technology that is necessary for development and production since these technology are so highly complicated that no individual engineers owned all technology. However, this clearer view will be enough to make firms to change its strategy. For example if the rivals are clearly dominant in that technology area, firms will try to diversify the product in which they can get an advantage, thus it will promote the diversification of products as well as by way of the new technology which they acquired through information exchange. On the other hand, Japanese big firms, who are depending on indirect information exchanges/diffusion, which are prevalent in Japan, tends to facilitate rivalry in an excessive way, as Yonemura et al (1995) explain this role of indirect and "fuzzy" information.

<Basic factor linkage>

US firms linkage is not limited to vertical and horizontal linkages. Iansiti et al. (1996) found that US firms are trying to connect its R&D with scientific fields. Also Semiconductor Research Corporation (SRC) was formed in 1982 to create linkage with
universities. However, this paper does not examine this topic further.

(3) Korean Industry Structure and its Technological Linkages Changes

(a) Background of technological linkages changes

Background of the Korean firms’ entry into semiconductor industry was the crisis appearing in the heavy and chemical industry in the late 1970’s. (Chen, 1996) Following government five-year plans, they entered this industry in the early 1980’s, but the situation surrounding the Korean semiconductor industry in the late 1980’s was quite different not only from that of the US but also from the that of the Japan two decade ago, when Japanese firms were also in their catching-up process. In the late 1970’s, Japan has an enough and growing domestic market, while Korean firms did not have enough its market even in their late 1980’s. In other words, no big environmental changes, at least in terms of domestic market or technology, to push up the industry existed. This fact can raise one big question. Why were Korean firms able to grow without domestic market? Most of people point out the entrepreneurism of Korean chaebols (Kim, 1997) Others points point government spending for its research and development program. I will examine this question from the point of view of technological linkages of industry.

(b) Vertical industry structure and its linkages

<Industry Structure and its Linkages– the Relationship with Downstream Industry>

Korean semiconductor industry is export-oriented. Table III-10 shows the production and export of semiconductor in Korea. The proportion of export is gradually decreasing, partly because of this technological spillover from semiconductor industry through domestic vertical linkage, but still its dependence on export is high level.
Table III-10. Production and Export of Semiconductor in Korea

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>425</td>
<td>1,155</td>
<td>5,104</td>
<td>14,800</td>
</tr>
<tr>
<td>Exports</td>
<td>415</td>
<td>1,062</td>
<td>4,541</td>
<td>11,720</td>
</tr>
<tr>
<td>Exports/ Proportion</td>
<td>97.6%</td>
<td>91.9%</td>
<td>89.0%</td>
<td>79.2%</td>
</tr>
</tbody>
</table>

(Source) Korean Development Bank (adapted from Kim (1997))

Why Korea was able to achieve this rapid growth of this industry without visible market in home, which is seems to be a disadvantage for Korean industry in terms of transaction costs that would be an eventual barrier across the border. There may be two keys of the reason why they succeeded in spite of this disadvantage. One of the reason is their focus on less custom oriented products, namely memory or DRAM. Korean industry depending 85% on MOS memory and 72% on DRAM in 1993. (EIAJ & SIRIJ, 1996). Since DRAM is a commodity good with definite specifications, as can be seen from the existence of spot market, marketing efforts of DRAM to the world does not need much close technological linkages with customers as that of other semiconductor especially as customer-oriented products do. Because of this too much dependence on memory products, Korea is still a net import country of semiconductor products.

The other reason of their success is their marketing offices including R&D facilities which they established in the United States. As soon as they decided to enter into semiconductor industry in the early 1980's, they formed semiconductor subsidiaries at the Silicon Valley almost at the same time. Table III-11 shows these subsidiaries. These subsidiaries, where many Korean American engineers were employed, played an crucial role as technological linkage with US market for collecting marketing data on technical matters for export their products as well as for acquiring cutting edge technology. In this sense, Korean firms was succeeded in internalize and localize the US market through

*15. Many analysts point out the role of US-Japan Semiconductor Arrangement, which have increased the DRAM prices of Japanese industry in US market artificially, and gave Korean firms a opportunity to crack in the US market and to achieve their learning curve rapidly.
close across-border technological linkages created by their subsidiaries.

Table III-11. US Semiconductor Subsidiaries of Korean Firms

<table>
<thead>
<tr>
<th>Firms</th>
<th>Subsidiary</th>
<th>Location</th>
<th>Date of establishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyundai</td>
<td>Hyundai Electronics America</td>
<td>Santa Clara CA</td>
<td>March, 1983</td>
</tr>
<tr>
<td>Samsung</td>
<td>Samsung Semiconductor, Inc.</td>
<td>Santa Clara CA</td>
<td>July, 1983</td>
</tr>
<tr>
<td>Goldstar</td>
<td>United Microtek, Inc.</td>
<td>Sunnyvale CA</td>
<td>July, 1984</td>
</tr>
</tbody>
</table>

(Resource) Chen et al. (1996)

Recently, they have established their marketing and R&D subsidiaries also in Japan (Hyundai in 1990, Samsung in 1997 under construction) (*16) Moreover, they are also establishing manufacturing plants in the US. For example, Samsung established a plant in Austin, Texas. This trend is not only for Korean firms but also Japanese firms. The Wall Street Journal (1997) explains that “the main reason companies locate (plants) here (the US) today is to close customers, to competitors and to the cutting edge of technological changes." In this sense, Korean firms as well as Japanese firms try to create vertical technological linkages with growing US market as well as to create horizontal linkages with developing US technology, thus their “foreignization" is advancing in terms of not only marketing and technology but also of production.

<Industry Structure and its Linkages— the Relationship with Upstream Industry>

The Korean industry also might have an disadvantage on its linkage with SME industry. Its equipment suppliers are so weak that the Korean industry is heavily depending on imports of its equipment (around 90%); 50% from Japan, 30% from the US and 10% from Europe. (Kim, 1997) Heavy dependence on Japanese import reflects its dependence on DRAM. The import of these high tech equipment was useful in their catching up process to transfer technology from abroad, but not for their technological development. Although the localization of equipment is gradually proceeding over time,

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*16. Both of firms have already established their "pure" marketing offices (not including R&D) in Japan in 1983.
as can be seen in Table III-12, it is still relatively low level. The reason of this gradual increase may be mainly due to technological trickle down effect, which is driven by growing semiconductor investment through their domestic technological linkages, but also due to some joint ventures with foreign equipment firms, which are attracted by growing Korean market. These joint ventures are strong especially in wafer fabrication equipment segment, which needs higher technology. (EIAJ & SIRIJ, 1996)

Table III-12. Localization of Semiconductor Equipment in Korea

<table>
<thead>
<tr>
<th>Year</th>
<th>90</th>
<th>91</th>
<th>92</th>
<th>93</th>
<th>94 (est)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.4%</td>
<td>8.3%</td>
<td>10.8%</td>
<td>8.3%</td>
<td>14.3%</td>
</tr>
</tbody>
</table>

(Source) KSIA (adapted from EIAJ & SIRIJ (1996))

However, why were the Korean firms able to achieve not only to catch up to advanced semiconductor technology but also to develop a cutting edge semiconductor technology by themselves without domestic equipment supplier? For example, in November 1996, Samsung announced that they succeeded in developing a prototype of 1G DRAM first in the world. (*17) Further examination must be necessary to answer this question, but probably the distinction with mass production must be necessary. Korean firms might have accumulated enough technological ability to create a leading-edge prototype within a laboratory through their R&D efforts. However in order to achieve mass production, they may still need to import equipment, especially from Japanese equipment firms who are leading in their high grade technology of lithography which is vital part of DRAM technology development. In this regard, generally speaking, Korean firms may still have a disadvantage in producing leading-edge technology products first in the world because Japanese firms have closer linkages with its lithography equipment firms than Korean firms have.

This lack of domestic equipment firms is pointed out by many analysts that as a

*17. However, some other firms also announced its success of 1G DRAM earlier than Samsung. For example NEC announce its development in academic field. Probably this depends on its development stage, reliability of products, or other factors. (Nihon Keizai Shimbun, 1996)
vital missing in their advantage (Kim, 1997), and its necessity become more and more vital for next step of technology development. Korean government has recognized this problem and tried to promote this industry. As for the semiconductor material industry, there were some governmental R&D project even in the early 1980's. Promoting material industry was also a part of its 4M project. Partly due to the result of these efforts (and partly as a result of joint ventures with foreign firms), the localization of these materials are also increasing. (1992; 36%, 1993; 37%, 1994(est.);48%) (EIAJ & SIRIJ, 1996) On the other hand, the effort to promote equipment industry is more recent, probably because equipment technology needs much higher capability than that for materials technology. A project called Electro 21 was launched in 1992 to subsidize research and development expenditure especially of middle class firms (approximately 4.8 billion won). Its recent G7 project also including the development of equipment with some suppliers. This project will be discussed later. The government expecting to increase the share of domestically produced equipment up to 50% by 2001. (EIAJ & SIRIJ, 1996, Kim, 1997)

(c) Horizontal industry structure and its linkages

<Industry Structure>

As can be seen in Table III-7, the structure of the industry of Korea is somewhat similar to those of Japan in terms of heavy concentration on big three firms, notably known as chaebols. As same as Japan, this concentration may enable them to concentrate of high volume products, mainly DRAM. Korean fourth firm, Daewoo, one of the big chaebols but far smaller firms in terms of semiconductor production, is rather focusing on custom oriented products, as Japanese 11th firm is. This concentration on big firms is quite contrast with Taiwan semiconductor industry, where small firms are pervasive and focusing on design intensive products. (Chen et al, 1996, Mody, 1990, Schive, 1990)

Although their businesses in total are still relatively small in size compared with Japanese counterparts, they can afford to invest in semiconductor industry through transferring their profit from other businesses, which practices are different from that of Japanese firms. This may be because of its family owned structure of Korean firms as opposed to inner-promoted CEO of Japanese firms. Risk taking business practice and its entrepreneurship, which are often raised as Korean firms behavior, may be due to the same
reason above.

However, there might be another two big differences from those of Japanese companies, other than its management practice. One is the number of firms. Korean semiconductor industry has only 3 big firms while Japan has more than 10 firms. The other is the diversification of products. Samsung and LG, which had only limited experiences of electronics at least at the end of 1970's, have now a relatively fair amount of electronics industry right now (for example, in the case of Samsung, almost one fourth, of which semiconductor occupies most), but their dependence on electronics is still relatively small percentage compared with Japanese counterparts. Hyundai has still few electronics products other than semiconductor.

These differences might be disadvantage for stimulating domestic rivalry. In addition, they are not competing each other in domestic market but rather in foreign market. This may also be a disadvantage in terms of "visibility" of rivals' activities in market. How did Korean firms overcome these disadvantages? It might be relatively reasonable to understand, say, the success of Samsung due to its success of management strategy. However, it might have been impossible for other two chaebols and also Samsung to grow with such a rapid pace, without mutual stimulation through some information exchanges among these firms with each other, as described below.

<Technological Linkage>

In spite of these disadvantages in horizontal structure, rivalry between chaebols are severe, as Porter (1990) described that "the essential underpinning of Korean industry's advantage is the fierce and even cutthroat rivalry." He also observed that "each chaebol is prone to enter every important Korean industry, especially if one of the others does so." In this regard, each chaebol might listen to every step rivals take. Probably this is because, and that is why there are considerable indirect information circulating about rivals activities around Korean industry.

Although some general information exchanges through media can be observed, there seems to be relatively only a limited number of deep channels for indirect exchange of technical information, as compared with that of Japan. Its trade association, Korean Semiconductor Industry Association (KSIA), was only recently was created in 1991. The major objective of this trade association is to coordinate private companies' opinions into government policy. The role of academic societies, as direct information exchanges
between engineers or researchers, is still relatively small, at least of the number of the publication at ISSCC’94 and IDEM’94 is concerned, despite its recent technological development. (just 0 and 7 publications of Asian firms respectively, while US and Japan has around 50 publications each. SIRIJ, 1995)

In order to compensate these weak technological linkages, which will make it difficult to co-develop with rivals, two efforts can be observed. First, is the creating strong linkage with foreign firms. As mentioned before, all of three firms established their subsidiaries in Silicon Valley. These subsidiaries played an important role to collect the data on technological information of US firms as well. Of which, Samsung’s case is interesting. During the period of 1M DRAM development, Samsung divided into two teams; one is a team in Korea, and the other is a team in Silicon Valley. Samsung gave them similar tasks to let them compete with each other. Kim (1997) describes that "In a sense it was competitive, because both were to the pursue the same goal; in another sense, it was collaborative, because they were to exchange information, personnel, and results." In other word, this strategy is to create strong technological linkage with foreign land in order to attain co-development within firm. He concluded that this strategy is the one of the main reason of Samsung success compared with other firms.

The other effort is the government role as a intermediary of technological information exchange. This was important in technical indirect information exchanges, especially 4M project and consequent projects, which will be mentioned later.

(4) Summary of the Chapter

As seen from the above, the patterns of growth in the United States and Korea are quite different.

The pattern of the US industry’s growth is mainly based on the co-development through vertical technological linkage. Stimulated by economic growth and the competition with Japanese industry, growing domestic market and technological development based on high design intensive technology interacted with each other positively. This vertical co-development with downstream (market) and upstream (SMEs) industry was enhanced by closer vertical technological linkages than before, partly by firms’ effort to "Japanization" and partly by efforts at SEMATECH, both of which
contributed US industry structure to raise its technological development ability to the level of that of Japanese.

This co-development of vertical relationship was supported by its horizontal co-development system, which was shaped by its own horizontal structure. Following the competition with Japanese, US firms were able to shift to high-design oriented products through its own direct exchange based horizontal technological linkages, because of its existence of small firms and diversified big firms. This horizontal structure, as well as vertical structure (computer-related market), was so different from that of Japan that Japanese firms were not in a preferable position to diversify their products and to create co-development pattern of computer-related industry, design-intensive products, and software-related equipment, as the US was. Instead, Japanese firms have still an advantage in some segments such as DRAM or consumer-related segments through its own vertical linkages with its downstream industry and upstream industry (especially, lithography). US firms may have also an advantage in terms of strong basic factor technological linkages with its world class universities in this regard.

Table III-13. US Growth Pattern and Technological Linkages

<table>
<thead>
<tr>
<th>Technological Linkages</th>
</tr>
</thead>
<tbody>
<tr>
<td>domestic structure</td>
</tr>
<tr>
<td>growing market</td>
</tr>
<tr>
<td>strengthening SMEs</td>
</tr>
</tbody>
</table>

=> diversified technological development

(Remark) Parenthesis is the linkage with abroad.

On the other hand, the pattern of Korean industry’s growth is rather based on its co-development through horizontal technological linkages. Since there was no home market, they had to focus on commodity goods, especially on DRAM, and try to create technological linkage with foreign market through their outposts. They also had to import equipment from foreign firms. Rather these upstream and downstream industry have began to grow because of trickle down effect from the growing semiconductor
industry through its domestic vertical linkages, in which government played a role.

The main force which led Korean firms to develop technology rapidly was domestic rivalry among big firms. Although their industrial structure was suitable for DRAM development, horizontal technological linkage was relatively weak in general. This linkage was improved during this period and became main force of their development pattern, partly because of strengthened linkage with foreign land through their subsidiaries and partly by domestic linkages created by the government projects, which will be discussed in detail.

Although their success of DRAM was remarkable, it does not mean there was no problems. Too much dependence on DRAM is actually hitting Korean industry as well as their economy as a whole in this recent DRAM recession. The government, as well as the industry, has recognized this problem well before and has tried to create connection, especially with researchers in government laboratory and universities researchers, especially for non-memory area by way of creating high-skilled human resources for designing. The government is projecting the dependence on DRAM will be reduced up to 59% in 2000 and 40% in 2005 (85% in 1993). (EIAJ & SIRIJ, 1996)

Table III-14. Korean Growth Pattern and Technological Linkages

<table>
<thead>
<tr>
<th>domestic structure</th>
<th>Technological Linkages</th>
<th>domestic structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>gradual &lt;= growth of market</td>
<td>(linkage with foreign market)</td>
<td>big firms</td>
</tr>
<tr>
<td>gradual &lt;= growth of SMEs</td>
<td>(import/ JV government project)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(technological acquisition)</td>
<td></td>
</tr>
<tr>
<td>=&gt;</td>
<td>concentrated technological development</td>
<td></td>
</tr>
</tbody>
</table>

(Remark) Parenthesis is the linkage with abroad.
Chapter 4. Roles of Consortia in Technological Linkages of Industry

(1) Consortia as a Technological Linkage

In this chapter, consortia's role in creating the effective technological linkages will be examined. At the first two sections, the paper will examine how the consortia in the United States and Korea were organized so that technological linkages within the structure of the industry were suitable for their industry structures. Then I will compare these two projects with Japanese VLSI project in the late 1970's. Table III-15 shows basic comparison among these projects and recent Japanese project, which will be discussed in the next part.

Table III-15. Comparison of Semiconductor Consortia

<table>
<thead>
<tr>
<th>name of project</th>
<th>VLSI project (Japan)</th>
<th>SEMATECH (U.S.)</th>
<th>VLSI(4M,16/64M,256M) (Korea)</th>
<th>ASET (Japan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>period</td>
<td>76–80</td>
<td>87–(96)</td>
<td>86–89–93–(96)</td>
<td>96–2000</td>
</tr>
<tr>
<td>finance</td>
<td>$350m/4yr 40%</td>
<td>$1900m/10yr 50%</td>
<td>about $600m/10yr 42–57%</td>
<td>about $120m/5yr 100%</td>
</tr>
<tr>
<td>government</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>participants</td>
<td>5</td>
<td>14</td>
<td>3/(4M)</td>
<td>16</td>
</tr>
<tr>
<td>SME</td>
<td>no</td>
<td>contract</td>
<td>(yes/256M)</td>
<td>yes</td>
</tr>
<tr>
<td>joint lab?</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>government</td>
<td>large</td>
<td>small</td>
<td>large</td>
<td>medium</td>
</tr>
<tr>
<td>involvement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source) various sources

(2) SEMATECH in the United States

(a) background
SEMATECH, which was formed in 1987 — about a decade after Japan’s VLSI project, was a product of close cooperation between government and industry, but its initiatives was made by the side of industry, especially by the Semiconductor Industry Association (SIA), its trade association which was established in 1977. Following an IBM’s study in 1986, which documented the rapid decline of US SME firms, SIA began to define the possibility of joint industry-government cooperation, which modeled Japanese VLSI project, and published a report in September 1986. This was almost coincident with a draft publication of the Defence Science Board of DOD in early October 1986, which called for the establishment of a U.S. Semiconductor Manufacturing Industry Institute. Lobbying efforts in Washington began in February 1987, and next month SIA decided the formation of SEMATECH, to which Federal legislation approved government funding on the same month.

SEMATECH’s original members were 14 firms, which compose 80% of total sales of US firms. These includes all of 6 big firms (Intel, Motorola, Texas Instruments, IBM, National Semiconductor, and AMD) and most of middle size firms (AT&T, Digital Equipment, Harris Semiconductor, HP, LSI Logic, Micron Technology, NCR, Rockwell International). The reason why they have not included small firms are partly because its membership due. (Grindley et al, 1994)

(b) initial planning

SEMATECH’s initial planning was to improve semiconductor manufacturing processing technology, which was vital for regaining back the MOS memory segments, by cooperating horizontally as well as vertically. For that purpose, SME suppliers formed SEMI/SEMATECH in September 1987 as a means to facilitate linkages between US SME suppliers and SEMATECH, and SEMATECH itself established its central research facility at Austin, Texas in 1988.

However this attempt was proved to be failed since direct horizontal cooperation will imply exchanges of each firm’s proprietary technology and lead to conflict with their own rivalry. After completion of joint laboratories at Austin, members began to complain on this agenda. Grindley et al (1994) described that;
Process technology expertise is central to the competitive advantage of individual semiconductor manufactures, and member firms were reluctant to share such sensitive information. The sophistication of the manufacturing technology of SEMATECH member firms also differed considerably, raising the danger that some firms could "free ride" on the contributions of technology leaders.

Because of this opposition, SEMATECH was forced to change its research agenda to focus on strengthening vertical cooperation between semiconductor firms and SME firms. By focusing on vertical cooperation, they thought they could avoid proprietary technology exchanges at least within members.

However, it does not mean that this change of agenda was agreed with all members. For some smaller firms with weaker capabilities in process technology, their main objective was to acquire this manufacturing process technology through horizontal cooperation. The withdrawal of Micron Technology and LSI Logic in 1992 from the consortium reflected their dissatisfaction in this regard. (Grindley et al., 1994) Harris Semiconductor left the consortium at the end of 1992 due to its shift of its strategy, and NCR lost its eligibility in 1995 due to its acquisition by Hyundai.

(c) organization

<vertical technological linkage>

Although they shifted their focus to vertical cooperation, this agenda shift did not always nullify the proprietary problems. There were still concerns on proprietary technology problems for SMEs firm that their proprietary technology would leak out to their own competitors through vertical linkage. Grindley et al. (1994) remarks,

Just as SEMATECH's original agenda for research on manufacturing process technology raised concerns by chip manufacturers over sharing information with competitors, sharing between SME suppliers and SEMATECH member firms has raised concerns among suppliers that proprietary information will be disclosed to competitors. One SME supplier, Invax, has sued SEMATECH for allegedly revealing sensitive technical information to a competitor.
In spite of these concerns, SMEs were generally satisfied with the relationship with SEMATECH. One of the reason is the fund flow of research contract from SEMATECH to SMEs, which had increased from 20% of total budget in 1988 to roughly 50% in 1991. In this sense, SEMATECH succeeded not only in correcting prisoners’ dilemma, at which US firms have been criticized for long, but also in promoting the exchange of this proprietary knowledge of SME by bypassing through strengthened vertical linkage. As for the correction in this prisoners’ dilemma, Green (1996) describes that,

In the past, semiconductor manufacturers have been reluctant to permit equipment suppliers to thoroughly examine how the equipment operated in the manufacturing environment because the device maker could incorporate incremental improvement into SM&E systems that could benefit rival semiconductor produces. This compromised SM&E advances by denying them an important test laboratory. SEMATECH has attempted to strengthen inter-industry relations by having consortium members share strategic goals, technical information, and some of the cost of new equipment generation with suppliers. In addition, the consortium built a fabrication facilities in Texas to provide a laboratory where new devices and equipment could be tested and refined.

SEMATECH’s main vertical program are four elements. One is the Joint Development Programs (JDP), in which SME firms get a contract from SEMATECH for new equipment (approximately 25% of funds for each project), and equipment testing and certification takes place at Austin, at members facilities or, in most case at SME’s location, mainly managed by SEMATECH employees. This account for 60% of total budget. Another is the Equipment Improvement Program (EIP), which is for current models for equipment. This program also takes place at Austin but most frequently at members facilities and at SME’s location. Third is the provision of "road maps", which suggest goals and timetable for achieving new technological development and facilitate planning by SMEs. These roadmaps are based on discussions among SEMATECH managers and member firms, and are open to public. A related effort by SEMATECH is the development of standards for equipment interface and for evaluation of equipment. This include a Computer Integrated Manufacturing (CIM) program. Last is the series of meeting and conference at various levels to improving communications between them
including Partners for Total Quality (PFTQ). (Grindley et al., 1994, Spencer et al., 1993)

<horizontal technological linkage>

Although SEMATECH emphasizes the vertical linkage with SME firms, it also facilitated horizontal information exchanges. For example, the road map making process mentioned above must be an information exchange process of what own firms and rival firms are thinking about for the future of technology development, although it's intention was to facilitate the technological development of SME firms. They do not have to disclose their own proprietary technology with each other but it makes the rivals' strategy clear.

In additions that, organization itself include the mechanism of horizontal information exchanges. In 1995, 220 of over the 800 personnel employed at SEMATECH (about 27 percent) were assignees from member firms. These assignees may have played an important role in exchanging information directly without caring or recognizing the leakage of proprietary knowledge. Actually these horizontal information exchange are positively evaluated by members, as General Accounting Office report (1992) mentioned that SEMATECH is widely credited by member firms with improving communication within the semiconductor industry. (Angel, 1994) Even from SEMATECH side, these assignees abilities are highly appreciated, as William Spencer, the CEO of SEMATECH, observed that assignees tend to come from the upper half of the employees in its member companies. (Spencer et al. 1993) This may be because member firms can get benefit from sending high quality assignees to SEMATECH, by correcting prisoners' dilemma in horizontal non-proprietary information exchanges successfully.

<basic factor linkage>

Another important area in information linkage is with universities researchers through creation of Semiconductor Research Corporation (SRC), which was formed in 1982 but funded by SEMATECH after its creation to flow its fund to Semiconductor Center of Excellence (SCOE) in 27 universities and other laboratories, so far.

(d) government role

In general, government involvement in the consortium management is minimum.
Although Advanced Research Projects Agency (ARPA) of the DOD had been funding substantially for SEMATECH (50% of the total budget, or $100 million/year for first five years and $90 million/year for later), the government gave SEMATECH "maximum operational discretion". (Corey, 1997) Although there were some cases that ARPA gave concern, for example, when SEMATECH shifted its research agenda away from longer-term and more fundamental issues to short-term equipment development (Katz and Ordover, 1990), in general, "ARPA representatives monitored the consortium's progress closely, but did not involved in policy formulation, R&D planning or governance", as Corey (1997) observed. This flexibility might contribute the effectiveness of this kind of consortium. (Grindley, 1994, Corey, 1997)

Then is it possible to justify the government funding in terms of neo-classical economics? For justifying government funding, first, at least the government portion (a half) of result of research cooperation government portion of funding must be available to anyone who wants it. In this regard, SEMATECH's policy became relatively sound after 1991, partly in a response to criticism against its policy. As for the intellectual property, SEMATECH originally licensed its knowledge exclusively to members for two years, after which it would become available to all other U.S. firms at nominal royalty charges. (Grindley, 1994) SEMATECH also prohibited SME from selling the products with its assistance to non-members firms for one year. These exclusiveness was abolished in late 1991 but SEMATECH members still have the priority in ordering and receiving SEMATECH-funded equipment (US. GAO, 1992), effectively giving them the option of acquiring new equipment 6–9 months in advance of non-members and the advantage through familiarity of the equipment. (Grindley, 1994)

However, SEMATECH announced in October 1994 to seek an end to funds from the federal government. Partly this is because members feel they made a deal with government at the time of formation (Spencer, 1994), as Robert Noyce, the founder of SEMATECH, testified at a congressional hearing that government role is temporary. (Corey, 1997) However, this may make difficult to understand justification of government funding itself, without ending the whole project. Considering that Robert Noyce reflected that SEMATECH might not have been launched without government assistance, the role of government was a "catalysis", as Grindley (1994) described, to create system to trust in vertical technological cooperation and to promote horizontal information exchange, both of which overcome prisoners' dilemma.
(3) Korean Projects

(a) background

Contrary to the US, it was mainly Korean government who had its initiative in promoting semiconductor industry since the late 1970's. In 1976, the government published their fourth five year plan (1977–81), in which they identified semiconductor industry as a strategic industry, and then formed its Korean Institute of Electronics Technology (KIET) (later, Electronics and Telecommunication Research Institute (ETRI), a government R&D institute (GRI) of Ministry of Communications (MOC).), which established its liaison office in Silicon Valley and opened its first semiconductor manufacturing facilities in 1978, 5 years before Samsung did. Following this plan, the government published next fifth five year plan (1982–86) and Semiconductor Industry Promotion Plan, which includes plans for subsidized capital and tax benefit for semiconductor investment, the creation of industrial estate, increased funding for government research project and continued import protection. These might be a clear signal for Korean firms to take a risk to enter into the industry. By 1986, Samsung and other Korean firms had acquired 64K, 256K and even to 1M DRAM technology, basically through purchasing and adopting foreign technology as mentioned at section 1.

However, there arose growing concerns for the next step of 4M DRAM development since the cost of R&D was increasing exponentially and a technological difficulty as well as that of acquiring foreign technology was anticipated in the middle of the DRAM debacle in 1984–85 (Kim, 1997, Howell et al., 1988). With these backgrounds, President Chun Doo Hwan's advisors convinced him in 1985 to "orchestrate a massive development project involving every important Korean company in the (semiconductor) business" (Electronics, 1987). Then, in April 1986, the ETRI announced the Korean Semiconductor Cooperative Research Project, a Korean version of VLSI project, known as 4M DRAM project (1986–89, W87.9B or about $110M). In this regard, this project was a government-lead project, as can be seen from the fact that this project was called "the Blue House Project". (Electronics, 1987)

In order to attract and give incentives to firms, the government contributed 57% of the total expenditure and subsidized the industry portion by government-guaranteed and
low-interest loan. This project was followed by 16/64M DRAM project (1989–93, W190B or about $250) and 256M DRAM project (1993–, W195.4B or about $240M). The latest project (256M) is a part of Highly Advanced National (HAN) project, called as "G7 project", which is named after the G7 group of advanced countries. This HAN project expects to spend about $1,450 million over ten years for semiconductor development. (Research Technology Management, 1992)

(b) initial planning

The focus of the project was the development of 4M DRAM. Initial plan was to develop its core technologies jointly at ETRI facilities because the concept of the project was "orchestrate a massive project involving every important Korean companies." ETRI invited researchers from the chaebols to participate in, but they were unwilling to work together. (Bloom, 1992)

This seems to be a natural reaction, considering the nature of chaebols' "cut-throating" severe rivalry. Actually this argument was a controversy even before the project began. In 1985, company officials denied the rumor of joint projects and insisted that the idea to divide the task in project was absurd, while a government official commented that it was necessary to establish an information exchange system, although top secret should not be exchanged. (Howell et al, 1988) As a result, although the government did announce the joint project, each firm formed its own group, trying to succeed independently, so the ETRI program had to be dissolved. (Bloom, 1992)

Consequent projects had same formations. The government organized a similar consortium, involving ETRI as a coordinator, but the three firms had an enough ability to do research by themselves that they refused to share their knowledge with each other, thus the consortium was virtually a mechanism to distribute the government's R&D subsidies. (Kim, 1997)

(c) organization

<horizontal technological linkage>

However, it does not mean there is no horizontal "indirect" information exchange. ETRI's job in the 4M project was not to do R&D but to stimulate and coordinate efforts
of firms to develop the chips themselves. The project was useful not in terms of exchange of proprietary knowledge but of indirect information exchange that stimulate rivalry. Evans (1995) described that

The research was "cooperative" in a way that heightened the pressure to keep up with competitors. Representatives from each company's team get together on a monthly basis and compared progress (without sharing any secret specifics). ETRI monitored progress and dispensed loans in accordance with each company's accomplishments. The pressure to keep abreast of the progress of the other participants was perhaps as important a prod as the monetary incentive itself.

In this sense, the role of this project is to focus on single technology and then to "stimulate" rivalry with each other through promoting non-proprietary information exchanges. Probably because of this effect, not only Samsung but all of three firms were able to succeed in their technology development by stimulating each other.

Government was not always promoting rivalry among the chaebols in single technology but rather in a few comparable technologies. In the 4M project, they took different approaches (a stack structure, a trench structure and a hybrid structure.), probably because of a government direction. Watching Samsung and LG was successful in their 4M design, Hyundai had to changed its approaches to the one Samsung took. (Kim, 1997)

Since the role of the government was a stimulator of rivalry, the evaluation of the project may differ by evaluators. According to Evans (1995), Samsung acknowledged the project's usefulness and other chaebols admitted that, while they would have started work on a 4M DRAM sooner or later, the existence of the project made it sooner rather than later. On the other hand, Hobday (1995) determined that the core effort and investment was in-house, citing his interview with Samsung's engineers, few of whom mentioned ETRI unless prompted.

<vertical technological linkage>

Although the focus of this project was horizontal, there were also projects to promote SMEs. However, in general, they seems not to have focused their effort much on creating linkages, especially with equipment industry as compared with material
industry. For example, in the 4M project, there were three pillars; 4M DRAM, non-memory ICs, and supporting industries. But in this pillar of "supporting industry", the government was placing emphasis on material industries, such as development of high purity silicon, chemicals and specialty gases, rather than equipment industries. (Howell et al., 1988) In addition, the government set a lower tariff rate on equipment imported for R&D purposes (Amsden, 1989), which might not be favorable for equipment industry to create technological linkage. It has still set lower tariff rates on equipment (4 to 5%) than that of materials and parts for equipment. (8%) (EIAJ & SIRIJ, 1996) These linkages and tariff structure may be some of the reasons why the materials industry is relatively growing, while equipment industry hovers around in low.

Although the government have recognized the necessity of promoting equipment industry, it has been failed so far to create vertical linkage with domestic semiconductor firms. The government formed the Semiconductor Equipment Research Cooperative in December 1989 under the control of the Korea Semiconductor Equipment Association (KSEA), and ETRI proposed a US–Korea joint effort to develop equipment, citing SEMATECH as a model. (Howell et al., 1992) (*18) In 1992, the government launched a project called Electro-21 to promote research and development of electronics component and materials, including for semiconductor. (EIAJ & SIRIJ, 1996) However this project is rather stand-alone project, which may be not for creating linkage.

Recent effort for SME industry is within its 256M project, which composed of four pillars; process technology (for 256M), material technology, equipment technology, and advanced technology (which is a research done by ETRI). Although this third pillar, "equipment technology", has only one tenth of total budget, some domestic equipment firms in addition to three big chaebols are participating in the project. (EIAJ & SIRIJ, 1996) This may suggest that the consortium is now trying to create vertical linkage with equipment firms.

<Basic factor linkage>

As for the basic factor, there are also government's efforts. Recent agenda is to create linkage with universities and other organizations to train engineers with expertise

*18. Probably, this proposal have not been accepted.
especially in chip designing (non-memory project). For that purpose, the government enacted a law in 1995 to establish training center around the country. (EIAJ & SIRIJ, 1996) Although this project was made by strong request from KSIA, it seems to be that there are no specially efforts to create linkage with private firms, except with small firms.

(d) government role

As for the Korea’s case, the government has played a important role as a stimulator in creating highly effective horizontal information environment. The strategy was to send a signal and give an incentive to a specific single sector (e.g. DRAM) and to stimulate rivalry through indirect information exchange. Since this sector has some features that Korean industry can develop, such as commodity, necessity of large capital and dependence of manufacturing technology, the strategy was tremendously successful to trigger the Korean firms’ technological development. Despite its overall success, this strategy was not always perfect. This strategy might be one of the reason why they are now too much depending on memory products, especially in DRAM, as mentioned before.

It is difficult to estimate the governmental funding from the point of neo-classical economics. Probably, the justification will be to correct imperfect information between rivals, which tends to be in prisoners’ dilemma, and to focus their research on single technology/ segment, which needs some incentives since firms tend to diversify in perfect information. This aspect of focusing on single technology in horizontal structure might be preferable to develop a specific breakthrough technology, in contrast to SEMATECH’s failure in lithography through vertical cooperation, but not for diversification, as negative side of Korean development. This kind of subject might need further examination.

On the other hand, the government has failed to promote SME industry especially in its equipment industry at least so far despite its efforts. This may due to its failure in creating vertical linkage by enforcing stand alone projects without linkages and/ or uncoordinated with other policies. (eg. trade policy)

(4) Comparison of Both of the Projects and Japan’s VLSI project

(a) Background
Both of the projects were triggered by some sense of crisis in the industry and government. In the United States, it was external pressure. They feared that their market would be overtaken by Japanese firms. In Korea, it was rather internal lack of technological abilities. They thought they could not get into higher technological products, which needs to compete with firms in advanced countries. In this regard, Japan’s VLSI project had also some senses of crisis, which were both of external pressure and internal lack of technological abilities. At that time, the Japanese government had agreed to liberalize computer and semiconductor market, thus severe competition with US firms was expected. Also a Japanese company managed to get a secret document of IBM, in which its development plan of 1M DRAM was described. Since it was a time when Japanese firms barely moved to produce 4K DARM, this was tremendous technological threat for Japanese firms. (Callon, 1995)

However, initiatives of both projects are different. In the US, the industry side including SIA lobbied the government and public opinions and succeeded in acquiring the fund, while in Korea, the government proposed the project and gave the chaebols an incentives to participate. As for the Japan’s VLSI project, it was somewhat mixed. It was actually industries who wanted help from the government, but it was the government who draw up the draft of the joint research project. (Callon, 1995)

(b) initial planning

Initial concepts of both of the projects were the same. SEMATECH first tried to focus on memory manufacturing process technology through mainly horizontal collaboration at its central facilities in Austin. The 4M project first planed to do its research with horizontal cooperation among Korean firms at ETRI’s laboratory. Probably, these plannings were greatly affected by the widespread understanding that the success of Japanese semiconductor firms was due to its success of Japan’s VLSI project, in which horizontal collaboration was orchestrated by the government.

However, these initial planning were completely failed as mentioned before. Recent studies also show that even the Japan’s VLSI project was failed to create perfect horizontal cooperation. Japan’s Ministry of International Trade and Industry (MITI) first proposed to established a joint laboratory, but the industry was "horrified" to this idea.
After a tug-of-war between MITI and the industry, it was decided to focus on only "common and basic" technology at the joint laboratory so that the companies would not have to be afraid of exposing proprietary technology to their rivals, and to allow for funneling the funds directly to firms' own research laboratory. (Callon, 1995) It may be possible to deduce from these experiences that horizontal research cooperation at the joint laboratories is not easy to be formed nor effective as a research environment.

(c) organization

In order to avoid the proprietary technology problems, two projects took different approaches. SEMATECH took an approach to keep the joint facility but to change its agenda to vertical cooperation by subsidizing the equipment industry. The 4M project took an approach to keep horizontal but to give up its joint research. Japan's VLSI project also took another approach. It is same with SEMATECH in terms of its existence of joint laboratory, but it is still horizontal research for "common and basic" technology rather than vertical cooperation. Also it is same with the 4M project in terms of the fact that most of research (approximately 85%) was done at each company's laboratory. Table III-16 illustrates these shifts.

Table III-16. Shift of Consortia's Main Agenda in Technological Linkage

<table>
<thead>
<tr>
<th>vertical</th>
<th>horizontal</th>
<th>basic</th>
</tr>
</thead>
<tbody>
<tr>
<td>non-proprietary</td>
<td>4M project</td>
<td></td>
</tr>
<tr>
<td>proprietary</td>
<td>SEMATECH &lt;=</td>
<td>VLSI project &gt;=</td>
</tr>
</tbody>
</table>

These different approaches in their organization created different effects. SEMATECH created vertical linkages as well as horizontal direct information exchange at the joint facilities without worrying about its proprietary technology. The 4M project created horizontal indirect information exchange under the supervision of the government.
The effect of Japan's VLSI project was similar to the 4M project at first. Many analysts commented that the "success" of VLSI project was largely due not to joint laboratory to private firms' laboratories. Probably this is because of a stimulator effect of rivalry through horizontal indirect information exchange, as worked in the 4M Project. Actually, researchers had to present at open conferences and produce thick reports, and "of course the reports did not contain all the relevant information about know-how" (Callon, 1995), but this might be enough to stimulate rivalry among firms. On the other hand, as for the joint laboratory, it does not mean that the it was totally unnecessary for the success. It might be true that even limited to "common and basic" technology, the joint lab did not work well at first because of hostile among different firms' researchers. Companies also frequently refused to send their top researchers to the joint lab. However, "after two years (of four years project) the information flow increased because the advance of technology was so rapid; almost all the technology was new after two years." (Callon, 1995) This may indicate some these horizontal direct information exchange were finally activated because of advancement of technology.

On the other hand, the Japan's VLSI project, as same as the 4M project, did not have a mechanism to create vertical linkage, except the linkage as occasional subcontractor. Although this occasional linkage may have played a part as technological spillover (Young, 1994), the most of the equipment for research was imported from the United States. (Callon, 1995). The main differences with the 4M project were the existence of the potential firms with substantial technological level, and their very existing vertical linkage, known as *keiretsu*. Although 70% of equipment was imported at the time of the project began in 1977 but still have 30% of domestic production. Then during the project, SME firms (say, Nikon and Canon, now major optical lithography manufacturers) began to have a closer cooperative relationship through existing linkage with member firms (say, Toshiba) on a standardization or user requirement. (Young, 1994).

(5) Summary of the Chapter

From analysis above, three points can be raised as conclusions.
i) Horizontal proprietary technology exchange are difficult to achieve.

At their initial stage, all of three projects pursued horizontal proprietary exchange by doing research among members at joint laboratories, but all of them failed because of oppositions from members. Although it is unknown that this step is necessary as an "initial ceremony", this difficulty is in line with the theoretical view which predicts that leakage of proprietary information is vital loss for all of members.

ii) Consortia shifted their agenda so that they can improve a part of technological linkage which they needed most.

Following the oppositions from members, consortia shifted their agenda. SEMATECH for vertical linkage, 4M project for non-proprietary exchange, and VLSI project for basic and common research, as Table III-16 shows. These shifts are coincident with US growth pattern of vertical linkage and Korea’s growth pattern of horizontal linkage. Without saying each project has another role in these technological linkages, though it might be a minor. For example, SEMATECH and VLSI project promoted horizontal direct information exchange, while another Korean project (other than 4M project) tried to create vertical linkages.

iii) The main role of the government in consortia is to let firms out of prisoners’ dilemma.

Government role in SEMATECH was rather a "catalysis" of cooperation, while that in Korean role was a "stimulator" of rivalry by promoting indirect information exchange. Theoretically, these role may be to create cooperation in a prisoners’ dilemma.
Part IV. Conclusions and Recommendations

Chapter 1. Conclusions

(1) Main Conclusion

This paper has analysed the competitiveness change of semiconductor industry in order to find out the effectiveness of government-industry consortia. Two out of three questions that has been examined so far from the standpoint of technological linkages of industry: "What was the causes of recent changes of competitiveness?" and "How did government-industry consortia affect these changes?".

As summarized analyses at each chapter, main conclusions which can be deduced from the findings from these analyses are followings.

i) There are two distinct pattern of industry’s growth; vertical growth pattern (co-development pattern through vertical linkage) and horizontal growth pattern (co-development pattern through horizontal linkage).

Vertical growth pattern, which is co-development of domestic market and industry, is the pattern which US industry growth is based on. In the United States, although the decline of the US until the mid-1980’s were greatly exaggerated by the exchange rate, domestic market increase after mid-1980’s was enough to explain their strengthening technological level. This increase of technological level also promoted its market increase. This co-development pattern of market and technology can be observed also in the relationship between semiconductor industry and its equipment industry. Of course, even in this pattern of growth, its basis is horizontal rivalry.

Horizontal growth pattern, which is co-development among rivals, is the pattern that Korean industry was based on. In Korea, the main source of technological development was its rivalry among chaebols. Because of its increase of technological level, trickle down effect to downstream industry and upstream market can be observed.
ii) In addition to each firm’s efforts, consortia can be effective by creating technological linkage along with its development pattern.

It is hard to establish horizontal proprietary technology exchange program in consortia. All of three consortia analysed, at first, focused on technology of specific products by horizontal cooperation, but all of them are forced to change its program. In this sense, consortium cannot be an alternative of IPRs but a complement of IPRs. SEMATECH, then, took an approach to strengthen the vertical linkage, which was the pattern of the US industry’s growth. They refocused their program to strengthen vertical linkage, which has played a role to improve their weakness. It succeeded in creating "trust" between semiconductor firms and SME firms by cooperating each other, as well as facilitating horizontal information exchange voluntarily. Main government role was a "catalysis" for the purpose of creating this trust.

Korean 4M project took another approach to strengthen the rivalry between firms, which was a growth pattern of the industry and a sole advantage of the industry. They give up the idea to exchange proprietary technology and they refocused to facilitate rivalry by comparing the technological progress of the firms. The government role here is to play as a "stimulator" of rivalry by exchanging indirect information of rivals, as well as by giving an financial incentive to let them focus on specific products, which also played a role to promoting rivalry between firms.

In sum, consortia’s role in technological linkage is mainly to facilitate vertical exchange of proprietary technology and/or horizontal non-proprietary information exchange, depending on its growth pattern. Horizontal exchange of proprietary technology should be avoided, since this is the source of monopolistic profit and incentives to develop technology for firms. Therefore this part should be protected by intellectual property rights or firms own efforts to hide. Vertical exchange of non-proprietary information is basically a matter of market mechanism. However it still includes transaction cost problems, which may necessitate government to create technological standards or make a signaling efforts, as US and Korean government did. This last area needs further discussion, as will be mentioned later.
Table IV-1. Role of Consortia in Technological Linkages

<table>
<thead>
<tr>
<th></th>
<th>vertical</th>
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</thead>
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<tr>
<td>non-proprietary</td>
<td>market mechanism</td>
<td>(consortia)</td>
</tr>
<tr>
<td>proprietary</td>
<td>(consortia)</td>
<td>IPR, know-how etc.</td>
</tr>
</tbody>
</table>

(2) Implementation Problems

These two cases may be successful cases, but there are some points to be recognized in order to implement consortia effectively. Following three points can be raised.

1) **Success and selection of strategy may heavily depend on its industry structure.**

Background of US’s success was in its both vertical and horizontal industry structure. Its vertical structure — the existence of strong and growing downstream industry (especially computer-related industry) and upstream industry (including software-related sector) make US firms enable to co-develop with each other based on its horizontal structure — the existence of big and small firms, which enables firms to develop diversified technologies. These vertical and horizontal structures, which are suited for growing diversified computer related market, was the premises of success of US industry, which are contrast to Japanese structure.

Instead, success of Korean firms was based on its existence of large firms (*chaebols*) which are capable to mobilize their funds to semiconductor industry. Their success in DRAM is heavily depending on this industry structure, which is quite contrast to Taiwan firms, who are focusing on design-intensive products. Since Korean firms had few domestic market and SME industry, they had no choice to select a vertical growth pattern.

The role of technological linkage and consortia is to facilitate technological growth
which is based on its industry structure. A strategy against its own industry structure may hurt the growth instead.

**ii) Consortia may have its own limit.**

Consortia can be effective by organizing in a proper manner, but it does not mean that consortia can be omnipotent. It has its own limit. Vertical consortia like SEMATECH is possible because most of the invention of semiconductor equipment is made by semiconductor firms. It does not mean that all of the vertically related industries should form consortia. Moreover, this kind of consortia might have a possibility to make firms lose their flexibility in its buyer-suppliers relationship, as Japanese *keiretsu* has been criticized by US governments/firms. This need further discussion.

Horizontal consortia also might have a side-effect. Horizontal consortia can be effective for concentrating to develop on single or at least comparable technology by letting firms to compete with each other, but sometimes it may go excessively. Korean industry, which focused on DRAM, is the example. In this sense, Korea’s strategy might be good for its catching up process to crack in the world market in the mid-1980's but they might have to change its strategy more quickly to, say, create domestic upstream and downstream market.

**iii) Government role in consortia might include disseminating clear aims with flexibility and let firms to pledge commitment at least temporally.**

Since government role in consortia is "catalysis" of cooperation or "stimulator" of rivalry for the purpose of creating "trust" among member in a prisoners’ dilemma, they need to disseminate clear aims and make firms pledge a commitment so that firms can create trust with each other.

Both SEMATECH and Korean projects had clear aims. SEMATECH published technology roadmaps with technical goals by 2010, while Korean projects’ aims are clear; 4M project for 4M DRAM development, and so on. Clear aims can be created by close relationship with government and industries, and will let firms to know what they should do for research. SEMATECH was a result of close relationship through lobbying efforts,
and roadmaps were prepared by more than a hundred of representatives from industry and governmental agencies. (Corey, 1997) In Korea's case, it was more like top-down process from the government to industry, but usually the government and big chaebols are closely connected with each other. (Evans, 1995) This clear aims must be flexible since technological situation will change rapidly over time. In SEMATECH's case, government involvement was relatively small and gave private firms a "maximum operational discretion" and its road maps were revised several times. In Korean projects, although government role was strong since it has to let firms to focus on single technology, the period of each project was about 3 years each.

Moreover, in order to facilitate this "trust" between firms, governments have to try to let firms to pledge commitment for their own aims so that all member firms try not free ride but to develop technologies by themselves. Government role as "catalysis" or "stimulator" is in this part. This might be important because consortia tend to be formed at the time of "sense of crisis". This situation is preferable for forming cooperative research as theory suggests, but this is the time when firms are beginning to lose their confidences in their business to commit further. If firms lost their confidence, they tend to be trapped into vicious circle; this kind of pessimistic information prevails around the industry and firms tend to give up their "commitment", and again pessimistic information prevails. As mentioned before, information surrounding firms is not as perfect as market mechanism assumes.

Government role in this clear aims and commitment might be a "signaling" to correct this imperfect information through government-industry relationship, as well as to correct prisoners' dilemma. Governments commitment to involve in SEMATECH and the 4M Project at the time of their establishment stage might have been a clear signal for firms to commit their technological development.

From theoretical points of view, this government role in signaling is still ambiguous. For example, what kind of government-industry relationship can correct market information better than market mechanism? How this relationship can distinguish promising industry from declining industry? These kinds of institutional (or targeting) problems needs further discussion. At least, what can be suggested from these two cases is government role as catalysis or stimulator must be temporal. Government subsidies to SEMATECH will be end after its 10 years, but this length is debatable. In Korean projects, they might have focused too long in single segment.
Chapter 2. Recommendation for Japanese New Project

(1) Japanese Growth Pattern

Japanese growth pattern in the late 1970's and early 1980's was due to both strong rivalry in horizontal linkage and co-development of market and technology for consumer electronics products in vertical linkage, although the result of competitiveness was exaggerated by exchange rate,

Their strength was due to both horizontal and vertical. Horizontally, the strong rivalry was attained by its similar size and products of big firms, and this rivalry was heightened by its VLSI project in the former period and close information exchange was established in the latter period. Strong rivalry was important for DRAM export, which was same as Korean development pattern. Vertically, they are vertical integrated firms which includes consumer electronics divisions in their firms, and have traditional propensity to cooperate with SME industry through their keiretsus. This downstream linkage was useful to develop improved products for consumer electronics, while the upstream linkage contributed to foster the SME industry with high technological level, especially to create strong lithography firms.

This system worked well until the late 1980's, when consumer electronics industry was overshadowed by the rapid and radical development of computer and information related industry, in which the US had an advantage, and when Japanese superior strength in DRAM products was undermined by the emergence of Korean industry.

(2) Japanese Recent Movement for Linkage (*19)

About a decade after SEMATECH and 4M project, it is now the turn for Japanese industry who has a sense of crisis, because of those resurgence of the US industry and

*19. Sources of this and next section are mainly based on EIAJ & SIRIJ (1995, 1996) and author’s interviews with a MITI’s official.
the emergence of Korean industry.

Partly because of this sense of crisis (competitiveness changes), the Japanese industry is recently making a series of steps to re-create their vertical, horizontal and basic linkages by themselves. Three organizations were formed so far by private firms' initiatives. Electronic Industry Association of Japan (EIAJ) created a committee for middle term vision for semiconductor industry, and published a report in March 1994, in which they call for a creation of a think tank for semiconductor industry. Then Semiconductor Industry Research Institute of Japan (SIRIJ) was formed next month by major ten Japanese semiconductor firms, and began to study a possible strategy for the industry, which they called as Advanced Technology Launching Study (ATLAS). Through this ATLAS project, SIRIJ have made two proposals for creation of organizations so far. One is a report published in March 1995, which called for creating an organization to flow their funds to universities for the purpose of supporting training engineers and creating generic and creative technologies. This organization, Semiconductor Technology Academic Research Center (STARC), which is similar to SRC of the U.S., came into birth in December 1995 by the ten firms. The other is a report published in March 1996, in which they called for an organization to collaborate with each other both in research for cutting edge and generic technology and in evaluation of future generation equipment. At the stage of draft, they requested MITI to share the funds for research, and it was decided that most of the research part were funded to a different organization by the government. Thus this expected organization were born in divided. Association of Super Electronics Technology (ASET) was formed in February 1996 in order to do research for new technology by getting a contract from the government (through New Energy and Industrial Technology Development Organization (NEDO), a government R&D organization), and also Semiconductor Leading Edge Technologies, Inc. (SELETE) was established by the ten firms to do the rest of the functions, mostly the evaluation of equipment. The latter organization is similar to SEMATECH of the US, and expected to play a role as international coordination with, say, SEMATECH. Note that it may be interesting that SELETE, a similar organization as SEMATECH, was formed without government funds as opposed to SEMATECH itself. This may indicate that Japanese firms are accustomed to vertical collaboration that they did not need any "catalysis" of the government to form this kind of organization.
(3) Japan's New Project (ASET)

(a) Background

Japanese government decided to give a contract with Association of Super Electronic Technology (ASET), a research consortium, to let it do research on three technological areas; semiconductor technology, magnetic storage technology and electro-optic display. Main focus of the project is the semiconductor, which comprise roughly 60% of total budget. This project, which began in 1996, about a decade later than SEMATECH and Korean 4M project, was the only Japanese project focused on semiconductor for two decades. There might be two backgrounds on the formation of this consortia, although they have not always made them clear, partly because of political/diplomatic consideration. One is the declining competitiveness of Japanese industry against the U.S. and Korean counterparts, which are mentioned earlier. The other is the technological difficulty which can be forecasted in the near future. As miniatuarization of semiconductor manufacturing process proceeds, an innovative breakthrough must be necessary. The Wall Street Journal (1996) said "Japan's Ministry of International Trade and Industry is so concerned about the possibility of a slowdown that it has sponsored a $30 million research program focused on technologies that could replace conventional semiconductors."

With these backgrounds, this consortium was formed mainly by private initiative, as mentioned before. This includes the establishment of the joint laboratories. This might be quite different from other three project analysed before. One of the reason of this might be because they have remembered the experience of the success story of VLSI project. SIRIJ's report (1996) praises that "(these organizations recently created) are the first collaborative organizations since VLSI Research Association (of VLSI project), (which will be).... a turning point of the history." In a sense, they have learned experience of trusting with each other in prisoners' dilemma. Another reason why members create joint laboratories by themselves may be the fact that SIRIJ, a place for firms to communicate with each other, has played a role to create trust between member firms. The report forementioned also reflects "When SIRIJ was established, our main concern was whether 10 rival firms could talk each other at all, and it seemed that collaborative
activities for manufacturing process technology was far and far away. However, as discussion proceeds, it became clear that which should be competed and which should be cooperated with each other." In this sense, "initial planning" stage that was described for previous three projects was not made at the level of government but of trade association, that is SIRIJ. However, there might be also some mechanism in its organization, which make it possible to create joint laboratories voluntarily.

(b) Organization

ASET's semiconductor part, participated by 16 firms, are made of 6 research items, of which 4 items are for lithography-related. (two for EB, one for X-ray and ArF each.) Table IV-2 shows this.

Table IV-2. Formation of ASET project

<table>
<thead>
<tr>
<th>Research Items</th>
<th>Participants</th>
<th>Laboratories</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>&lt;Lithography&gt;</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Electron Beam (EB) Direct Writing System</td>
<td>Fujitsu – Advantest Hitachi</td>
<td>(Individual)</td>
</tr>
<tr>
<td>2. Super High Precision Mask Fabrication System (for EB)</td>
<td>Toshiba – Toshiba Machine JOEL</td>
<td>(Individual)</td>
</tr>
<tr>
<td>4. ArF Excimer Laser Lithography</td>
<td>10 firms</td>
<td>Joint Lab (Hitachi)</td>
</tr>
<tr>
<td><strong>&lt;Plasma&gt;</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Plasma Physics and Diagnostics</td>
<td>10 firms</td>
<td>Joint Lab (Hitachi)</td>
</tr>
<tr>
<td><strong>&lt;Cleaning&gt;</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Physical and Chemical Cleaning</td>
<td>TI Tsukuba SPC</td>
<td>(Individual)</td>
</tr>
</tbody>
</table>

(Source) ASET, interview with a MITI's official

<Horizontal technological linkage at joint laboratories>

As can be seen in Table IV-2, three research items out of six are done at two joint
laboratories (NTT and Hitachi), which may enhance direct technological information exchange, but usually tend to be prevented by rivalry. The reasons why they agreed to form joint laboratories voluntarily may be following two points.

i) technological nature

Each of three research items has a reason that they preferred a joint laboratories. As for the X-ray lithography research, it is only the Nippon Telephone and Telegraph (NTT)'s laboratory which has a synchrotron to generate X-rays. Therefore, members want to do individually but they have to use the joint laboratory. As for ArF lithography, the focused technology is limited to the bottleneck point, in which all members are interested. Since they each have already had enough parts of technology for ArF lithography and they have already been familiar with at least the fact each of member are interested in this technology through discussion at SIRIJ, they do not have to worry about these other parts of technology to be leaked out through this joint research. They also expect to finish it soon. As for the plasma technology, they focused only on research on basic and scientific technology, of which much of the budget goes to universities.

ii) small size

Although the budget was 100% funded by the government, absolute amount of budget is quite small compared with other three projects. MITI hopes to fund about $200 million in 5 years, of which the semiconductor part is approximately 60%. Although it spent more than $60 million initially for buying equipment for research, partly boosted by supplement budget at that time, it will be expected that annual budget for these 9 research items is about more or less $10 to $15 million unless additional supplementary budget is admitted. This number is quite small compared with firms' individual budget for R&D.

Partly because of this, the number of researchers in the joint laboratories are also small. Each firm sends only one or two researchers to each joint laboratory. Therefore much of the research may be done at individual firms' laboratory by their own funds, and they do not have to much worry about their own proprietary technology to be leaked out.

<Vertical technological linkage at joint laboratories>

As long as memberships are concerned, joint laboratories have no equipment firms
members. Actually, the consortium examined the possibility to let them in the consortium as members, but gave it up because of proprietary knowledge problems between equipment firms. Instead, they are cooperating with the consortium as suppliers.

<Horizontal and vertical linkages at individual firms' laboratories>

As for the research at individual firms' laboratories, these are similar with the pattern of Korean 4M project, but there are two main differences. One is that they include equipment firms, some of which are the joint with their keiretsu firms. This objective may be to create vertical linkage. Unlike joint laboratories, these vertical linkages work because the diffusion of proprietary does not occur much among equipment firms. The other difference is that there are relatively only a small number of firms which are participating each research items. Two EB lithography research items are participated by only two group each, and the cleaning research item has also only two firms. Of these pairs, one of the firms are not semiconductor firms but only a equipment firm. Although the former items might compete with other lithography technology, such as X-ray or ArF, the rivalry might not be heightened so much in these formation.

(4) Government Role and Recommendations

<Strategy for Japanese Industry>

Japanese industry has two obstacles facing right now, as mentioned before. One is the relatively weakening competitive position of Japanese industry. The other is technological difficulties lying ahead. In order to attack these obstacles Japanese may need both of strategies; vertical led pattern of growth and horizontal led pattern of growth. First, in order to create strong and stable technological infrastructure (SME industry) to support the co-development of the industry, strong vertical linkage is necessary. Although the technological capability of Japanese industry has not been weakened at least in its absolute level, as analysed before, since their capability is depending on its inherited structure of keiretsu, it may be imperfect and somewhat lacking of flexibility. In this sense, it may reasonable to make an institution, like SEMATECH, so that vertical linkage will be strengthened.
Of course this strategy does not intend to follow the US’ success on design intensive products. It is true that Japanese industry want to produce design intensive products as US firms do, but since the success of US industry on this design intensive products is deeply rooted in its horizontal structure — the existence of numerous small firms, it is difficult for Japanese industry to create advantage by creating vertical or horizontal technological linkages through forming R&D consortia. Indeed, Japan’s MITI is now trying to promote venture industry, but it might take a long time. This might be a rather a matter of basic factor technological linkages — linkages with universities or government laboratories, although further study must be necessary.

Second, in order to breakthrough the technological difficulties, strong horizontal rivalry is necessary. Although rivalry of Japanese semiconductor firms are already very hard, aiming and concentrating on a few technology while heightening its rivalry will be effective to reach its objective. In this sense, horizontal technological linkages like Korean 4M project will be helpful for that purpose.

Table IV-3 shows the comparison of cooperative organizations in the three countries by their functions, that is horizontal, vertical, and basic factors. As can be seen, the role of ASET can be defined as to breakthrough technology rather than to create the basis for co-development of vertically related industries.

Table IV-3. Comparison of Technology Related Organizations

<table>
<thead>
<tr>
<th></th>
<th>Japan</th>
<th>United States</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>vertical</td>
<td>SELETE (1996)</td>
<td>SEMATECH (1987)</td>
<td>(G7)</td>
</tr>
</tbody>
</table>

<Government Role>

From government point of view, if an industry itself want to exchange technological information and if it will not harm the rivalry, that will be welcomed. As can be seen from the history, the joint laboratories of ASET was proposed by industry, therefore government should respect this idea. However, considering that the aim and the position of the project are to create breakthrough technology, this aim can be effectively attained
by promoting rivalry through indirect information exchange. The government role here is as a stimulator of rivalry, as same as Korean 4M project. The role of the government in stimulating private R&D through this project may be true as an officer in MITI observed the industry that "the government R&D money has an effect to induce the private R&D activities. The fact that the government is committing semiconductor technology itself seems to be persuasive for companies’ executives to draw more funds for R&D from the company’s budget." This targetting effect should be deliberately made with close consultation with private firms so that this might not be a market distortion excessively, like Korea’s DRAM’s case.

<Recommendations>

From these points of views, recommendations for ASET project will be two large points; to make aims clear and to stimulate rivalry for these aims.

i) Make technological aim clear, sound, and flexible.

Technological focus in ASET may be sound. It is mainly focusing on lithography, in which technological obstacle lies ahead and in which Japanese industry has already in a strong position. This focus will be preferable in terms of avoiding the failure of SEMATECH, which spent much money on lithography where the US firms were losing its position, and in terms of following the success of Korean 4M project, which focused on a DRAM segment, in which Korean firms had a potential to grow.

However, one of the problem as a premise for stimulating rivalry is that the technological aims of the project seems not to be clear. Although one of the reasons may be a long history of trade conflicts, in which US industry and government have been criticizing Japanese technology policy as unfair, clearly stated aims of the project are vital in order to make the project effective. In this sense, Korean projects had clear aims, such as developing 4M DRAM by 1989, and so on. Even in the US SEMATECH, they have produced their "road maps" as their technological aims. These technological aims should include near-terms aims so that rivalry will be heightened and flexibility will be ensured. Korean projects are basically three-years project, and road maps of the US also address near term aim and have been revised several times. Flexibility is important especially in the industry in which technological progress is rapid.
ii) Stimulate rivalry

As mentioned before, as long as industry wants to cooperate to exchange technological information, it will be fine. However even so, the consortium must have a mechanism to stimulate rivalry between firms so that government funds are not converted into a just subsidies for each firm.

As for the joint laboratory, collaborative research should focus on voluntary direct information exchange rather than forced exchange of proprietary knowledge. Concretely speaking, X-ray lithography research at NTT joint laboratory might be fine as a place to acquire X-ray and its data and to make a technological conversation among researchers, but research at individual laboratory should be emphasized, and results at these individual laboratories compared with those of rivals and aims mentioned above. As for the ArF lithography technology, the end of the project should be decided since this research is near term project and if it takes a long time they may lose incentive to innovate it.

As for the research at individual laboratories, more participants should be encouraged. The pairs of firms without rival relationship will not enhance rivalry among firms but make funds as a direct subsidy without any incentive to upgrade technology expect by its monetary means. Moreover they will not have an incentive to disclose the details of the research projects.

Vertical relationship may be sound. SME firms’ position as suppliers for joint laboratories will keep their proprietary technology and gives incentives to upgrade their technology. This may be enhanced more by competitive as well as cooperative procurement of equipment among these suppliers. Grouping at individual laboratory also is also fine in terms of keeping their proprietary technology secret, but it must be recognized that there might be a possibility of losing flexibility of firms. Basically, these cooperative aspects of vertical linkages will be enhanced at SELETE as a vertical technological linkages institution.
Appendix. Analysing the Causes of World Share Changes

Changes in the competitiveness as a world market share by industry based on nations can be divided into three factors; one is the static effect or market growth factor, in which no changes in market linkage or relative technological level is assumed. This factor composes two factors; pure market growth factor and exchange rate factor. The other is the dynamic effect or market penetration effect, in which no difference in market growth by regions are assumed. Mathematically, these can be defined as follows.

\[
\begin{align*}
S_{\text{world sales}} &= S_d (\text{sales in domestic market}) + S_f (\text{sales in foreign market}) \\
S_{i \text{(sales of industry based on nation i)}} &= S_{id} (\text{sales in domestic market}) + S_{if} (\text{sales in foreign market}) \\
nation \text{ i's world share (w)} &= \frac{S_i}{S} \\
&= \frac{S_{id}}{S} + \frac{S_{if}}{S} \\
&= \frac{S_{id}}{Sd} \cdot \frac{Sd}{S} + \frac{S_{if}}{Sf} \cdot \frac{Sf}{S} \\
&= (\text{sid})*(sdf) + (\text{sif})*(sf)
\end{align*}
\]

where,

\[
\begin{align*}
nation \text{ i industry's share in domestic market} &= \frac{S_{id}}{Sd} = \text{sid} \\
domestic \text{ market share in world market} &= \frac{Sd}{S} = \text{sd} \\
nation \text{ i industry's share in foreign market} &= \frac{S_{if}}{Sf} = \text{sif} \\
foreign \text{ market share in world market} &= \frac{Sf}{S} = \text{sf}
\end{align*}
\]

Therefore,

\[
\begin{align*}
\Delta (w) &= (\text{sid})* \Delta (\text{sd}) + (\text{sif})* \Delta (\text{sf}) \\
&+ \Delta (\text{sid})* (\text{sd}) + \Delta (\text{sif})* (\text{sf})
\end{align*}
\]

In this formula, the upper formula means the contribution of market growth factor,
a growth portion in which no change in market share in each (foreign and domestic) market is supposed. The lower formula means the contribution of market penetration factor, which explains the effect of changes in relative productivity level and the linkage with other market, supposed that each market growth rate is same.

The upper formula can be divided further into two.

\[(sd) \triangle (sd) + (sif) \triangle (sf)\]
\[= (sid) \{ (sd)_{n+1} - (sd)_{n} \} + (sif) \{ (sf)_{n+1} - (sf)_{n} \}\]
\[= (sid) \{ (sd)_{n+1} - (sd)_{n+1} \} + (sif) \{ (sf)_{n+1} - (sf)^{n+1} \}\]
\[+ (sid) \{ (sd)_{n+1} - (sd)_{n} \} + (sif) \{ (sf)^{n+1} - (sf)_{n} \}\]

where

(siden+1 is the domestic market share in the world market at the year n+1.
(sfen+1 is for the foreign market share.
(sdn+1) is the domestic market share in the world market at the year n+1, but each market share is adjusted supposing that there was no changes in exchange rate from the previous year n. (that is, each market share change from previous year (n) was subtracted by exchange rate change at the market from previous year.)
(sfn+1) is for the foreign market share.
(sdn) is the domestic market share in the world market at the year n.
(sfn) is for the foreign market share.

Mathematically, this formula can be rewritten like follows.

\[(sid) \triangle (sd) + (sif) \triangle (sf)\]
\[= (sd) (sf) \{ (sid)-(sdf) \} \{ (\triangle xd)-(\triangle xf)\}\]
\[\quad + (sd) (sf) \{ (sid)-(sdf) \} \{ (\triangle sd')-(\triangle sf')\}\]

where

(\triangle sd') is (\triangle Sd')/Sd', where Sd' is domestic share measured by local currency.
(\triangle sf') is for foreign share.
\((\Delta \text{xd})\) is \((\Delta \text{Xd})/\text{Xd}\), where \text{Xd} is the exchange rate of local currency.
\((\Delta \text{xf})\) is for the exchange rate at foreign market.

In these formulai, the upper formula is the exchange rate factor, while the lower formula is the pure market growth factor. In actual calculation, the lower formula can be acquired by subtracting exchange rate factor from market growth factor.

For Figure III-2 and Table III-3, Semiconductor Industry Association (SIA)'s data was used. This data comprises four markets (North America, Japan, Europe, and Asia/Pacific) and three industries (America-based, Japan-based, and others). Exchange rate used are Japanese yen for Japanese market (this is most important in exchange rate factor since US and Japan is the dominant markets in the world and the dollar-yen exchange rate has changed more drastically than any other currencies in this periods), and German mark for European market as representative. I used the US dollar for Asia/pacific market since some of Asia/pacific currencies are more or less linked with the US dollars and no representative currencies exist, and these market are relatively of little importance.
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