14 Analysis of Behavior to Carry Out R&D and Patent Filing under Evolutionary Game Theory(*)

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This study focuses on the trade-off between the incentive for R&D and the adverse effects of monopoly resulting from the granting of a patent right, and analyzes a model of economic theory that explicitly takes account of the influence of these factors on social welfare. While integrating into the model the negative effects on the economic growth rate arising from the "strength of a patent right" and "the very existence of a patent right," which have not been clearly defined in previous theoretical studies, this study introduces factors of evolutionary game theory into the process of deciding the volume of R&D investment, and considers an endogenous decision on R&D investment to be made by firms. In this study, exogenous parameters, such as the strength of a patent right and the strictness of the criteria for the granting of a patent right, are interpreted as policy variables, with a view to finding out the qualitative nature of the policy variables that can maximize social welfare that is the economic growth rate applied as an indicator. In addition, consideration is also made as to how a policy decision affects economic growth in the context of determining an optimal duration of a patent right when regulations are eased so as to allow different durations of a patent for different sectors.

I Introduction

This study provides an analysis, conducted by applying a general equilibrium model, of how the strength of intellectual property rights affects the economic growth rate. Among previous studies, those advocating theoretical models that conclude *the stronger the intellectual property rights, the better* are dominant. However, these studies cannot be evaluated as having given sufficient consideration to the issues regarding *monopoly* and *externality*, which should have been generally considered when developing a theoretical model that takes account of the strength of intellectual property rights.

Externality is one of the major reasons why intellectual property rights are necessary. Supposing that no rights are granted for R&D achievements, those who have successfully developed new technologies by spending an enormous amount of money would face the *free riding* problem—a third party who has made no contribution would imitate such newly developed technologies. If firms set their R&D level on the expectation that their achievements would possibly be exploited by free riders, the equilibrium level would be lower than a socially desirable level. As a means to minimize losses in social welfare due to free riding, it is necessary to grant some monopoly rights to those who have contributed to technology development.

On the other hand, monopoly is not a favorable state in the context of economics. The monopoly suppliers, who have price-controlling power, would be motivated to hold supply below a socially desirable level to manipulate the price upward, thereby maximizing their profit. Rules for intellectual property rights must be made while giving consideration to the trade-off between the adverse effects of free riding and those of monopoly, and an economic model that is to give a theoretical basis for such rules must also be created in the same line.

Intuitively, it could be said that if intellectual property rights are too strong, the adverse effects of monopoly would be too serious, whereas if intellectual property rights are too weak, they would give no incentive to carry out R&D; therefore, a socially desirable level of the strength of intellectual property rights would be between these levels. However, most of the existing theoretical models eventually support, although partially, the argument that the stronger the intellectual property rights, the better. This may be because factors such as the extent of free riding and the adverse effects of monopoly are

(*) This is an English translation of the summary of the report published under the Industrial Property Research Promotion Project FY2009 entrusted by the Japan Patent Office. IIP is entirely responsible for any errors in expression or description of the translation. When any ambiguity is found in the English translation, the original Japanese text shall be prevailing.

given only as exogenous parameters. From such viewpoint, this study develops and analyzes a model, within a general equilibrium framework, which considers an endogenous R&D investment behavior related to intellectual property rights (more specifically, patent rights).

As mentioned above, undersupply is an adverse effect of monopoly, and the granting of patent rights may have caused another *adverse effect of monopoly*. In the fields where patent rights have already been granted to certain firms, other firms must carry out R&D in a manner that they would not infringe such existing patent rights. As a result, even when the same volume of R&D investment is made, the chance of successful development of new technologies would be smaller in those fields, compared with the fields where there are no such existing rights. Considering that technological innovation is one of the key factors for economic growth, excessive protection of patent rights might generate waste in investment and ultimately bring about a social loss. This element could be largely controlled by means of policy, that is, how to deal with patent applications for new technologies which cannot be regarded as being effective in improving productivity but involve inventive steps to some degree. This study explicitly adopts this element as one of the policy variables in the model analysis.

Next, in Section II, the report of this study briefly reviews the empirical and theoretical results obtained by previous studies, and then discusses the points that have not been sufficiently probed, especially in theoretical studies. Section III formulates a model and makes a brief optimization calculation. Section IV surveys the results of numerical calculations, and sees how policy variables affect the economic growth rate. Section V states the conclusion of the study and issues for future study.

Ⅱ Relationship with Previous Studies

The adverse effects of monopoly have already been suggested in empirical studies. It is a generally supported view that there is an optimal interior point for the "strength of intellectual property rights" that indicates, for instance, the length of the duration of a patent right, where those rights are not too strong or too weak.

On the other hand, as extended endogenous growth models, there are a number of theoretical models which investigate the relationship between intellectual property rights and economic growth. These models, however, involve many problems yet to be solved, such as that their conclusion is incompatible with the results obtained in empirical studies, or that they completely exclude factors that should be taken into consideration in an empirical context or include those factors only in a reduced form.

In previous theoretical studies, the "strength of intellectual property rights" is primarily understood in terms of "infringement of rights," and at the same time it is also interpreted in terms of the "duration of patent rights," as in the case of empirical studies. Intuitively, there may be a significant difference between the duration of a patent right and infringement as to how the economy is affected when these factors are changed. To the knowledge of the author, there is no general equilibrium model that explicitly takes into account the influence of each factor. Based on the previous studies, this study develops and analyzes a dynamic general equilibrium model that is an extended version of the model advocated by Horii and Iwaisako (2007)(*1).

Ⅲ Model

This section shows the formulation of a model. It sets up a general equilibrium framework in which agents, in each period, engage in work of some kind at firms, earn income according to the results of their work, and use such income for their consumption, and defines the growth rate of consumption per period as an economic growth rate, which can be regarded as an indicator of social welfare. One of the major objectives of this study is to figure out the level of policy variables that maximizes the economic growth rate in the model.

1 Households and production technology

Let us suppose a closed economy consisting of a finite number of homogeneous agents who live for an infinite period of time. First, the utility to be gained by agents (as households) from consumption is defined. The term "utility" in this context can basically be construed to be a synonym for the "level of satisfaction." A utility function has the following characteristics: (1) the degree of satisfaction increases as the volume of

(*1) Horii, R., and Iwaisako, T. (2007): "Economic Growth with Imperfect Protection of Intellectual Property Rights." Journal of Economics 90: 45-85.

consumption increases; however, the increased utility to be gained from each additional unit of consumption is larger in the case where the volume of initial consumption is relatively small, than in the case where the volume of initial consumption is relatively large; (2) supposing a fixed number of units of consumption, present consumption gives more satisfaction than future consumption, provided that other conditions are the same.

In order to consume something, we have to secure income in some way and purchase the final goods. We can obtain money by *engaging in work* (in a broad sense). Supposing that agents are given one unit of labor in each period, if one period is one day, one unit would be 24 hours or 8 hours, and if one period is one year, one unit would be 365 days or about 280 days.

As defined in detail in the next subsection, agents decide whether they use their units of labor by engaging in work as workers or engaging in R&D as researchers in appropriate sectors of their choosing, and earn income in the form of wages and the like, according to their work performance.

Final goods are produced by inputting an infinite number of intermediate goods. Those sectors that produce intermediate goods are labeled as points on an interval with a length of 1.

Intermediate goods produced in each sector potentially have different grades of quality. Although immediate goods produced in the same sector can be used for the production of final goods in the same manner irrespective of their grades of quality, the degree of their contribution to the volume of final goods produced depends on their grades of quality. Needless to say, the higher the grade of quality, the larger the volume of production. The degree of quality improvement achieved by one unit of technological innovation (defined later) differs among sectors, which can be divided into two categories, i.e. high-growth sectors and low-growth sectors. The difference exists in respect to the degree of increase in productivity through quality improvement to be derived from each R&D success. Such increase in productivity is large in high-growth sectors, whereas it is not so large in low-growth sectors. In principle, every firm can produce intermediate goods of any grade of quality within the sector that it belongs to, but when the volume of intermediate goods to be input is the same, those of a higher quality would have a greater influence on the volume of final goods to be produced. All sectors are homogenous. That is, if the same quality and same volume of intermediate goods are produced and input, they would have the same influence on final goods. If the quality is also taken into account, it is more desirable that the volume of input intermediate goods be even, compared with the case where there is disparity. For instance, the volume of final goods to be produced would be larger when a medium quality and a moderate volume of intermediate goods are produced and input in all sectors, than when a high quality and a large volume of intermediate goods are produced and input in half of the sectors and a low quality and a small volume of intermediate goods are produced and input in the remaining sectors.

Given that the technology for producing final goods is supplied competitively, in each period, the firm producing final goods decides its demand depending on the price of the intermediate goods of the respective grades of quality that are offered by firms in each sector, while providing households with final goods at a price that it sets so that it would gain no profit as a result of its profit-maximizing behavior.

One unit of labor is required to produce one unit of intermediate goods of any grade of quality in any sector. Therefore, in the case of production of intermediate goods in the same sector, only the highest quality of intermediate goods in that sector would be produced.

In each period, each sector can be either competitive or monopolistic. A competitive sector is a sector where no firm holds a patent right related to the technology for producing the highest quality of goods and all firms can produce and supply the highest quality of goods under the same conditions. A monopoly sector is a sector where one particular firm owns the technology for producing the highest quality of goods and other firms can supply only the second-best goods.

Since price competition occurs for the technology used to produce final goods, in a competitive sector, the price of goods would be lowered to a level where firms gain no profit.

On the other hand, price competition is rather moderate in a monopoly sector. The monopoly firm, which has an advantage with respect to quality, sets the price of its goods at a level that is slightly higher than the wage level, so that the firm can gain some profit. This does not mean that there is no ceiling on the price that the monopoly firm can choose. If the firm offers intermediate goods at too high a price, this would give an incentive to other firms in the same sector to supply a lower quality of intermediate goods at a lower price. To avoid such a situation, the monopoly firm would set its monopoly selling price at a level where it could gain the same amount of profit irrespective of whether or not other firms supply the second-best goods at a price where they would gain no profit. As a result, the volume of production would be smaller than that in a competitive sector.

Let us assume that all firms can produce the second-best goods. This assumption is a sufficient condition for the monopoly firm having no incentive to make R&D investment. This is called the *Arrow effect*, which means that the person who gains the monopoly profit would be less active in carrying out R&D. Since the Arrow effect is observed in actual economic activities, it is reasonable to use this effect as the condition for making an assumption.

2 R&D

Agents engage in work while choosing, in each period, to be an unskilled worker, researcher in a competitive sector, or a researcher in a monopoly sector. When they choose to be an unskilled worker, they engage in work for a uniform wage that is to be determined endogenously. When they choose to be a researcher, they acquire stocks of the firms in the sector that they choose, and make R&D investment. They would succeed in developing new technology according to the probability of successful R&D that is determined depending on their investment level. A patent is applied for immediately after a new technology is thus developed successfully, and among those researchers who have achieved success in R&D, only one researcher will be exclusively entitled at an equal probability, in the next period and thereafter, to any and all benefits that may arise from a patent right in the future. Irrespective of whether their R&D has been successful or not, if they choose to be an unskilled worker or a researcher in another sector in the next period, they sell off their stocks of that sector to which they have belonged. Assuming that the stock market is complete and efficient, the actual stock price would remain the same for all periods and all firms.

Individual researchers determine how much R&D investment they make in each period, from a shortsighted viewpoint as explained below. Every researcher accurately understands his/her own function of developing a new technology, but he/she does not know such function of others, and therefore he/she has no knowledge of how much R&D investment others will make in the current period and thereafter and at what probability others will be successful in developing new technologies.

When making conjectures, each researcher refers to the status as to how others in his/her sector have obtained patent rights, as observed in the past. More specifically, by observing the most recent average rate of obtaining patent rights (achieving R&D success) in each sector, each researcher determines that there is a possibility that other researchers in his/her sector may obtain patent rights at a probability equivalent to the relative rate in the sectors where the situation is the same as in his/her sector. Based on his/her conjectures, the researcher calculates at what probability his/her investment will lead to the successful development of a new technology and how much investment he/she should make to achieve this, as well as at what probability he/she will not be able to enjoy the benefits of a patent right because of others' success in developing the same technology, according to the conjectureed number of other researchers and the R&D investment level in the sector where his/her firm belongs. Then, the researcher determines his/her optimal investment level, while taking into account the actions that others are apt to take under the current circumstances.

(1) Competitive sector

Agents, who have chosen to be a researcher in a competitive sector, determine their own R&D investment level. When their investment is at the level of zero, they are never successful in technology development, and as they raise their investment level to infinity, their probability of success increases accordingly. Disutility becomes large as their investment level increases because they have to input their money and labor according to the investment level. Furthermore, the higher the investment level, the larger the increase in disutility derived from one additional unit of investment becomes.

Let us assume that researchers do not engage in joint research with others. Individual researchers' success or failure depends on their efforts independently. Every researcher, by choosing an appropriate investment level, maximizes the difference between the expected value of profit that he/she will gain from R&D according to his/her investment level, and disutility that is derived from such investment.

(2) Monopoly sector

The factors necessary for the analysis of a monopoly sector are defined in the same manner as those for a competitive sector described in the preceding subsection, with two exceptions: (1) in the monopoly sector, there already exists a monopolist who has no incentive to carry out R&D due to the aforementioned Arrow effect; (2) researchers other than the monopolist have a smaller chance of developing new technologies. When a researcher other than the existing monopolist achieves success in R&D, this makes it impossible for the monopolist to maintain the monopoly profit. This is called *leapfrogging*. The goal of R&D in a monopoly sector is to become the new monopolist and gain the monopoly profit in the next period and thereafter.

It should be noted that the ease of leapfrogging can be interpreted as a policy variable. In cases where the technology for producing the highest quality of goods already monopolizes the market, if a firm which has no right to that technology has developed a new technology through a research process that is far from efficient, there is a considerable range of policy options, between acknowledging such later developed technology as a new production technology, or including such new technology in the scope of the patent (the technical scope of the patented technology) so that an injunction may be issued against the sale of goods produced by applying said new technology. Leapfrogging would be easy if the policy is close to the former option, and would be difficult if the policy is close to the latter option. It is not easy to find an answer intuitively for the question as to which is better—protecting the existing highest quality of technology that has already been developed, or facilitating such a new technology developed by leapfrogging to be acknowledged. In the next section, numerical calculations are made by setting different levels of ease of leapfrogging, so as to find out a level which maximizes the economic growth rate.

3 Labor market equilibrium

The number of researchers in a sector depends on free entry to the sector in the relevant period. In general, as the number of researchers in the sector increases, it becomes more probable that one researcher, even when he/she achieves success in technology development, is unable to obtain a patent right because other researchers also achieve success. This not only lowers the R&D investment level in the sectors where there are many researchers, but also encourages researchers in those sectors to move to other sectors.

Intuitively, if working as an unskilled worker is not appealing due to a low wage, then all agents will wish to become researchers, in which case a necessary amount of labor for the production of intermediate goods cannot be secured. Therefore, firms need to raise the wage level so that their production activities in the current period will no be impeded. However, when wages are high, an opposite force occurs, acting to lower the wage level. As a result, at an equilibrium point, all agents could gain the same amount of expected profit, irrespective of whether they choose to work as an unskilled worker or as a researcher.

4 Evolution of economy

In the preceding subsections, various factors involved in the equilibrium of an economy per period are defined. This subsection considers dynamics in which an economy per period is repeated, and defines the transition of such dynamics that start from a given initial state.

A sector that is competitive in a certain period can change into a monopoly sector in the next period if a patent right is granted to one researcher in that sector. If no researcher is successful in R&D, the sector remains competitive.

In a monopoly sector, monopoly by the existing monopolist comes to an end due to leapfrogging or imitation. As defined above, leapfrogging occurs when any other researcher has achieved success in R&D. Imitation means that monopoly comes to an end upon the expiry of the duration of the patent right or infringement. It is relatively easy for the policy authorities to control the expiry of the duration of the patent right. Although the duration of a patent right is uniformly set as 20 years under existing law, the report of this study assumes that different durations can be set for different sectors, and analyzes the influence on the economic growth rate in cases where longer or shorter durations are set depending on sectors.

On the other hand, it is not easy for the policy authorities to control infringement. In particular, if the authorities try to reduce imitation to almost zero, they would have to set a sufficiently long duration for a patent right, and create conditions where imitation could rarely occur. For instance, in order to prevent the leakage of information relating to the production of the highest quality of goods, the authorities would have no choice but to impose constraints on free economic activities in some ways, such as by limiting the items of personal belongings that workers may carry with them when entering the factory, or setting rules that restrict workers from taking data from computers. In the report of this study, such constraints are represented by the assumption that the degree of quality improvement achieved by one unit of technological innovation, as defined in the beginning of the section explaining the model setting, depends on the probability of imitation in the sector. In order words, it is defined that constraints would be imposed when the probability of imitation is extremely small, and this results in a lower degree of quality improvement.

When imitation occurs in a monopoly sector, the sector changes into a competitive sector in the next period, whereas when leapfrogging and imitation occur simultaneously in that sector, it is assumed that imitation precedes leapfrogging. In other words, imitation deprives the existing monopoly firm of its rights, and another firm that has achieved success in R&D becomes a new monopoly firm and acquires monopoly profit in the next period and thereafter.

Based on the formulation shown above, it is possible to analyze the economic growth rate in a steady state after an adequate period of time has passed. In mathematical terms, this can result in a question to be answered by solving an autonomous difference equation that is independent from a time label.

The next section looks at the results of detailed numerical calculations.

Ⅳ Results of Numerical Calculations

This section looks at how policy variables and other parameters affect the results of numerical calculations.

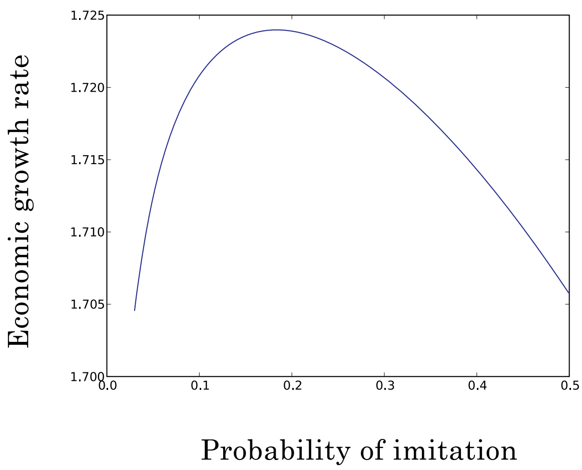
First, let us look at an optimal policy and its results, in the case that a uniform duration of a patent right applies. It is optimal to facilitate leapfrogging to the greatest extent possible. To be more specific, it is desirable that the policy authorities grant a patent right in a monopoly sector, to the greatest possible extent, even for a new technology which can be recognized as involving inventive steps to some degree but has actually been developed through a research process that is far from efficient. This nature is established irrespective of the level of growth potential of sectors. Intuitively, it can be explained that the positive effect of the facilitation of leapfrogging—that it will promote R&D in a monopoly sector and improve the quality of intermediate goods and thereby increase the supply of final goods—will significantly exceeds its negative effect of reducing the incentive for R&D by reducing the expected value of future profit after obtaining a patent right.

The density of population of researchers is higher in a competitive sector than in a monopoly sector, and it is also higher in a high-growth sector than in a low-growth sector. In a sector which is expected to bring about high-level R&D achievements and which therefore attracts a number of researchers, it is more probable that several researchers achieve success in R&D, but a patent right is granted to only one of them, while others cannot enjoy the benefit of their success. Consequently, once the number of researchers in each sector is fixed, the degree of attractiveness of the sector will be the same for all sectors when viewed from the standpoint of researchers.

This has an interesting influence on the volume of R&D investment. Irrespective of whether or not there are any constraints on the duration of a patent right, or whether the sector is competitive or monopolistic, the volume of R&D investment per researcher in a high-growth sector is on a par with that in a low-growth sector. In other words, the difference between sectors in terms of the level of growth potential is completely cancelled out by the difference in terms of the degree of researchers' entry into the sector (and the degree of their activity in research), and all sectors will be completely homogenous at the stage when agents who have chosen to be a researcher decide to make R&D investment.

The volume of R&D investment per researcher is larger in a monopoly sector than in a competitive sector. This may be because, in a monopoly sector, there are a smaller number of competing researchers, and they are more active in making investment as they have more chances to obtain a patent right if they succeed, even when their spending for R&D investment becomes relatively large.

The graphs below show the economic growth rate in a steady state, with the probability of imitation set at various levels.

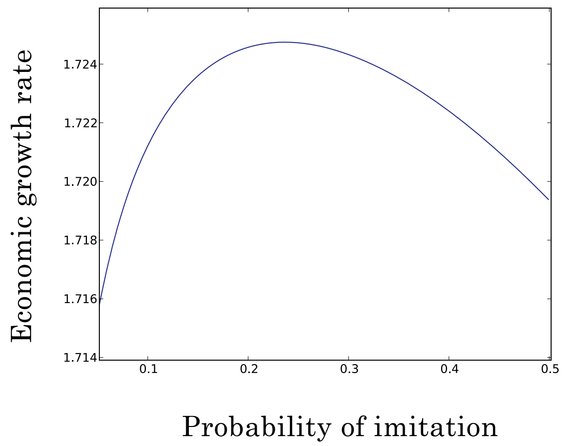


Next, let us assume an optimal policy in the case that there are no constraints on the duration of a patent right and that two types of durations can be set for different sectors. In the report, negative effects derived from removing constraints with respect to the duration of a patent right, such as social costs arising from the increased complexity of patent examination, are completely excluded from consideration. For this reason, it is trivial, without the need to make a specific calculation, that it is more beneficial if there are no constraints. However, when it comes to making a policy change, it is not trivial which policy should be changed and how it should be changed in order to realize an optimal policy. In this respect, an inquiry into the following results of numerical calculations may provide useful implications.

Here, the optimal policy is realized when $\bar{b}$ is set at the maximum.

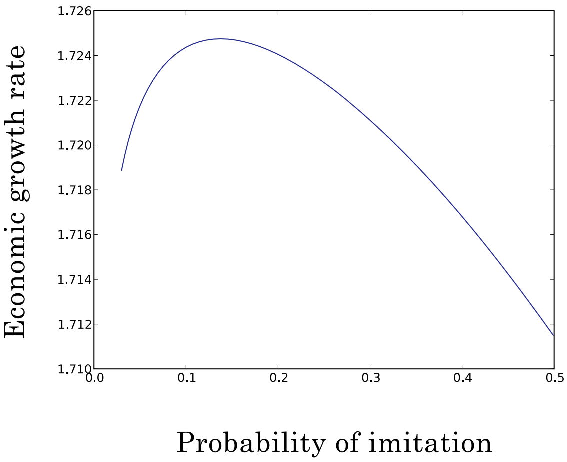
Under the optimal policy, the duration of a patent right is shorter in a high-growth sector than in a low-growth sector. Let us find out why, by comparing the results of two numerical calculations. In a high-growth sector, the duration of a patent right is shorter when there are constraints than when there are no constraints, the value that is expected from the granting of a patent right is lower, and the number of researchers acting in the sector is smaller. In a low-growth sector, said duration is longer, said value is higher, and said number of researchers is larger. To put it the other way round, when comparing the two sectors in the same period, it can be said that the high-growth sector offers higher monopoly profit than the low-growth sector, which means that the high-growth sector already has a good grounding for active R&D investment, and there is no need to give consideration from the policy perspective, such as setting a longer duration of a patent right. Of course, it can be argued that economic growth comes from technological innovation, and in order to effectively promote technological innovation, more incentives should be given to researchers to enter the high-growth sector. However, it is also true that if too many researchers come to one sector, it would happen very frequently that a number of innovative technologies that are similar to one another would be developed, although they would not additionally increase productivity, thereby causing a *loss*. The results of the numerical calculations suggest that such loss exceeds the degree of the aforementioned positive effect.

When the probability of imitation in either of the two sectors is fixed at an optimal level, while setting the probability in the other sector at various levels, the economic growth rate in a steady state is as indicated in the graphs below.



On the graph above, the probability of imitation in the low-growth sector is fixed at a certain level, the probability of imitation in the high-growth sector is on the horizontal axis, and the economic growth rate is on the vertical axis. This graph has a gentle curve compared with the graph subject to constraints, probably because on this graph, the probability of imitation in the low-growth sector is fixed and the policy change directly affects the high-growth sector alone.

On the contrary, in the graph shown below, the probability of imitation in the high-growth sector is fixed at a certain level, the probability of imitation in the low-growth sector is on the horizontal axis, and the economic growth rate is on the vertical axis. Its curve seems to suddenly become sharp around where the probability of imitation in the low-growth sector surpasses that in the high-growth sector.



An appropriate interpretation of this curve may be that the low-growth sector becomes too unattractive to researchers. The low-growth sector is basically inferior in attracting researchers who wish to engage in R&D due to the low level of productivity improvement, and in addition, if the probability of imitation is set at a high level from a policy perspective, researchers would not be attracted to the low-growth sector and the R&D level in this sector would become too low.

The three graphs shown above may give us the following policy implications. Supposing that the mutual influence among the parameters used in the report take on significance in the real economy, in the case where the duration of a patent right under existing law, 20 years for any patent, is an optimal level subject to constraints, it is desirable that after such constraints are removed, the duration of a patent right be made shorter in the sectors with higher growth potential. Careful consideration is required so as not to mistakenly apply a shorter duration of a patent right to low-growth sectors, which would have a considerable adverse effect on the total economic growth rate.

V In Closing

The report addressed the concept of "imitation," which has not been specifically taken into account in previous studies, and formulated it in the form of general equilibrium dynamics, by explicitly giving two interpretations: a "high likelihood of patent infringement" and a "shortness of the duration of a patent right." Through this approach, a conclusion that is consistent with the results of empirical studies has been obtained—the optimal degree of probability of imitation that can maximize the economic growth rate in a steady state is at a medium level. The report also analyzed an optimal policy in the case where the duration of a patent right is not necessarily required to be set at 20 years, which implies that it is desirable that the duration of a patent right be shorter in sectors with higher-growth potential.