# Session III
# OUTCOMES
# OF SCIENCE AND TECHNOLOGY

# ON MEASURING THE OUTCOMES OF SCIENCE AND TECHNOLOGY

**Aaron J. Gellman***

## Introduction

For many years there have been myriad attempts to link expenditures on science and technology (S&T) on the one hand and specific scientific or technological outcomes on the other. Such cause-and-effect relationships are always useful for planning, programming and budgeting purposes in any setting. For example, legislative bodies often seek to justify S&T appropriations on this basis; again, the R&D allocations of firms sometimes are said to be based upon relationships established through consideration of such linkages from past experience.

To the extent such efforts have been successful, they relate largely to associating very narrowly-defined expenditures with very specific scientific or technological results. For example, private investments in chemistry have been linked to specific innovations in paints and coatings. In the public sector, defense and space-oriented S&T expenditures have often been associated with various specified achievements. Even with the focus strictly on the physical manifestations of S&T efforts, the more aggregated the S&T expenditures being analyzed to determine their outcomes, the less successful has such analysis been. This is illustrated in Figure 1.

The connections become even more tenuous where S&T expenditures and investments are to be linked with their economic impacts. This is unfortunate because, especially in the private sector, increasingly such measures as return on investment and payback period are used to determine both the level of resources devoted to S&T and their allocation to various specific S&T pursuits. Figure 2 suggests that even where specific S&T expenditures are associated with specific S&T outcomes, it is difficult to judge the full range of *economic* impacts, either qualitatively or quantitatively. To the extent that this statement is too severe, it is only the case with respect to the top-most left-hand cell of the matrix that is Figure 2, for all other combinations, assessment of the full range of economic impacts has proved highly illusive and the greater the range of S&T investments and the broader the purview of the science outcomes and technological developments being assessed, the more imprecise and speculative are the identifiable economic impacts.

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Yet it is the economic impacts of S&T investments – defined more or less broadly – which are of greatest importance in guiding overall investment decisions in most cases. In the private sector, the economic outcomes are usually the most critical; in the public sector in the U.S., with growing budgetary constraints, this is becoming more the case than ever with respect to science, research and technological development. Consequently, economic and social measures of outcomes of S&T programs will be the focus of this paper. In general, concentration will be on the more novel means of measuring S&T outcomes.

**Measures Supporting Public Policy Formulation and Execution in S&T**

The reasons for attempting to measure the economic and social outcomes of science and technology differ between the public and private sectors. In the public sector, a much longer view must be taken and the benefits to be considered are broader and move varied than is required in private-sector assessments. For example, managers of public sector enterprises, as well as the citizenry at large, should be concerned with the implications of S&T investments (made in both the public and private sectors) upon such matters as:

- International technological leadership;
- Employment;
- National defense;
- Balance of trade;
- Productivity;
- National and international market competitiveness;
- Scientific publication;
- Patents issued.

Beyond this, however, it should be noted that S&T outcomes are amenable to evaluation in less conventional terms.

At any point in time, there are a finite number of goals or challenges being pursued by a nation. To a considerable extent, such goals or challenges are *time-dependent*. That is, specific challenges and goals wax and wane as a result of changed conditions in the world related to war and peace, environmental degradation, resource scarcity, etc. At every point in time, therefore, measuring the outcomes of S&T – both specifically and in general – should include the extent to which they support meeting the challenges and pursuing the goals of particular importance at the time. For example, certainly since the early 1970 s, energy conservation has been on the list. At present for the U.S., it surely contains at least the following:

- Amelioration of acid rain effects;
- Reducing atmospheric ozone depletion;
- Reversal of the Greenhouse Effect;
- Countering AIDS;

- Development and diffusion of advanced automated manufacturing techniques.

Turning now to some *time-independent* measures of S&T outcomes that warrant more than just a mention, there is the issue of national labor employment. Application of S&T outcomes has long been recognized as having a profound effect on the employment of the nation. What has often been overlooked is: (1) the implications of S&T efforts for the *quality* of employment opportunity produced ( rather than its mere quantitative dimension) and, (2) in times of labor shortage, S&T outcomes can, in fact, reduce pressures on the labor market from the demand side through the promotion of automation. With regard to the latter, then, it would have to be acknowledged that the way one gauges the labor impact of S&T outcomes will be somewhat time-dependent even though the overall labor issue is otherwise.

The outcomes of national S&T investments in terms of the formation and survival of small enterprise is especially important in the United States. After all, it is small business units which have been the hotbed of industrial growth and development in the U.S. for more than a century and the health of the small business community is a vital national concern. Therefore, the availability of S&T outcomes to small enterprise and the extent to which such S&T outcomes are advanced enough in the direction of practical application and are made available in a form amenable to exploitation by small business units is an exceptionally important measure of the value of such S&T investments for the nation.

The discussion just above pertaining to small enterprise serves to introduce a measure of S&T outcomes which has even broader applicability. This measure is their *diffusibility*. That is, are S&T outcomes pursued to the point where they are readily exploited by a wide range of enterprises such that the results are diffused rapidly into the economy with the benefits from such diffusion frequently being both widespread and significant? Diffusibility is not a trivial measure; growing U.S. experience in attempting to get S&T outcomes from government laboratories into the private sector strongly supports the contention that this quality of an S&T outcome is very often a function of the extent to which the S&T effort has been pursued and the manner in which the S&T results have been expressed and made relevant to one or more markets. As diffusibility is enhanced, S&T outcomes should "rate" higher than where the opposite is the case.

**Private Sector Issues**

The measures applied to S&T outcomes relevant to the private sector frequently differ from those of importance for public sector decisionmaking. For example, whereas at the level of the nation S&T outcomes which are highly and broadly diffusible are to be greatly prized, in the private sector, the opposite is generally the case. When a firm invests in its own resources in S&T, most often it does so in order to gain a measure of monopoly power or competitive advantage in the markets it serves. This result will obtain if such S&T outcomes are available only to the individual firm for some extended period. This can come about through the maintenance of trade secrecy or the judicious use of patents; or the situation may be one where the outcomes of the S&T investment are sufficiently *appropriable* to the investment made to achieve such outcomes.

In any event, what is likely of greatest value to the individual firm in terms of appropriability differs from national goals for S&T outcomes, especially those arrived at through the investment of some quantum of public funds. That is, the private sector generally seeks to invest resources in S&T to produce outcomes which are highly appropriable to the investor; S&T investments with public funds are judged best, in the usual circumstances, when the outcomes are highly diffusible to many firms and agencies. Therefore, in judging the outcomes of S&T, there should be some understanding of the motivation of those making the investment and of what constitutes a desirable outcome on their scales of value. As noted, this is very much a function of whether such investment comes from the public sector or the private sector.

Public and private goals are not always at odds, however for example, both the public and private sectors will give high marks to S&T outcomes which address highly leveraged problems of the day such as energy conservation and improved manufacturing performance at present. A firm with an S&T outcome that puts it ahead of its competitors from both a technological and marketing stand-point in such an area will be deemed successful by those in both the private and public sectors. In the later case, this is so at least as long as the private sector exploiter of the S&T outcomes does not have too much monopoly power over too long a time.

Two measures typically and properly employed in the private sector to judge S&T outcomes are revenue growth and market share position. In fact, revenue expansion is more employed as a measure of S&T performance in the private sector than it ought to be. The focus should clearly be on profit enhancement rather than revenue growth. Although with new products and services made possible through the exploitation of S&T outcomes, profit margins tend to be higher than average for a firm and revenue expansion becomes a measure which approximately parallels profit growth, it nevertheless is safer to use the profit based measure than the revenue-based one since it is profits that assure the long-run survival of an enterprise.

With respect to market share, care must be exercised because the meaning and value of market share enhancement will change over time. For example, to increase market share in a declining market may merely reflect staying in the market too long while competitors pull out. Yet market share continues to be a prominent measure of S&T returns for many industries and firms (and sometimes for countries, as well).

**Several General Points**

In both the public and private sectors, S&T outcomes with broad applicability to many industries should be assessed somewhat differently than S&T outcomes that have implications for a narrower industrial spectrum. For example, S&T outcomes pertaining to advanced electronics must be recognized to impact many more industries, firms and markets than, say, an S&T outcome that leads to an improvement in tires. This is far from a new phenomenon in industrialized society; machine tools played a similar role in the late 19th century to that of microelectronics in the late 20th century.

The foregoing is not intended to belittle the less dramatic S&T outcome so much as it is to point out that the so-called generic technologies have much greater leverage both on the fate of the nation and on individual entrepreneurial units than do S&T outcomes with far narrower applicability. It is not a question of "high-tech" versus "low-tech" either; such terms have come to be more political than anything else. Rather, it is the breadth of applicability that warrants the most attention when assessing and comparing the S&T outcomes that underlie various products and services. Not surprisingly, those technologies that warrant the most attention becomes the most difficult to asses in terms of their overall economic value.

While S&T outcomes need to be evaluated on both an individual and collective basis, the dynamics of firms and of nations cannot be ignored. Consideration of such dynamics requires estimation of the outcomes over time – specific events over many years and perhaps decades. In this connection, an S&T outcome that is the result of a commitment to a reliable, continuing and appropriately changing research agenda is more significant – both for a firm and a country – than would be the same specific outcome arrived at without such an agenda. The continuing programs are important because they strengthen a nation's and a firm's ethic for innovation. Those countries and enterprises with an on-going commitment to S&T convert S&T outcomes more efficiently and more quickly into products and services than do others. In significant degree this is because the former nations and enterprises have an underlying infra- structure in terms of both institutional and human resources oriented towards S&T achievements and the exploitation of S&T outcomes.

Finally, it is suggested that a highly underutilized technique for measuring the outcomes of S&T investments is "counterfactual analysis." Such an approach begins by asking the questions, "If a given S&T outcome had not been realized at the time it was actually generated, what benefits would society (or an enterprise) have foregone?" The technique poses a classical "but for.." question and pursues the answers with vigor. If our abilities to measure the outcomes produced by investments in science and technology development are to be sharpened, routine employment of the counterfactual approach can expand the availability of the analytical skills necessary for identifying and measuring such outcomes in ways relevant to both public sector decisionmaking and management. This approach also offers opportunities to explore in an efficient and effective manner the "black box" of linkages between S&T investments on the one hand and their economic and social outcomes on the other.

Figure 1

MEASURING S&T OUTCOMES

THROUGH PHYSICAL MANIFESTATIONS

| | A Specific Science Outcome or Technological Development | An Enterprise's Science Outcomes or Technological Developments | A Nation's Science Outcomes or Technological Developments |
|---|---|---|---|
| Specific S&T Efforts | Considerable Success | Limited Success | NA |
| Collection of S&T Investments (e.g., An Enterprise's) | Considerable Success | Considerable Success | NA |
| Broad Range of S&T Investments (e.g., A Nation's) | Very Limited Success | Very Limited Success | Limited Success |

NA=Not Applicable

Figure 2

MEASURING S&T OUTCOMES THROUGH ECONOMIC IMPACTS

| | A Specific Science Outcome or Technological Development | An Enterprise's Science Outcomes or Technological Developments | A Nation's Science Outcomes or Technological Developments |
|---|---|---|---|
| Specific S&T Expenditures | At Best, Most Direct Impacts | At Best, Most Direct Impacts | NA |
| Collection of S&T Investments (e.g., An Enterprise's) | At Best, Most Direct Impacts | At Best, Most Direct Impacts | NA |
| Broad Range of S&T Investments (e.g., A Nation's) | Very Limited Success and then Only Most Direct Impacts | NA | Very Limited Success with Results Limited to Early and Obvious Impact |

NA = Not Applicable

# ACADEMIA'S ROLE IN ECONOMIC DEVELOPMENT

**Chris W. Le Maistre***

Rensselaer Polytechnic Institute is unique, in the proactive role it has played, in encouraging entrepreneurship and the economic development of its region; Troy, New York, which was the birthplace of the industrial revolution in the United States. Troy was the Center of a thriving industrial community which included foundries, steel mills, and shirt factories. However the last fifty years saw a major decline that extended to nearby Schenectady, where the American Railroad Company closed down in the 1950's and the General Electric Company has moved much of its manufacturing to other locations. In the last ten years there has been a resurgence in the local economy with the emergence of many small high technology companies. This is in accord with the atomization of industry noted in other regions, namely a change over from a few large megalithic corporations employing thousands, to many small specialized companies employing a few hundred people each. In our region Rensselaer Polytechnic Institute has played the role of catalyst in bringing this about.

In 1977 "Rensselaer" created its first "Center" with support from the National Science Foundation. This quickly grew to be the Center for Interactive Computer Graphics fully supported by industry, at a level of approximately $1.6 Million per year. In 1988 the Center changed its name to the Rensselaer Design Research Center.

The Center for Manufacturing Productivity and Technology Transfer was formed in 1978 with funding provided by industry. Today this Center is doing in excess of $6 million worth of industrially sponsored research.

The Center for Integrated Electronics was formed in 1981 and is focused on Very Large Scale Integrated Circuit Design. It was recently provided a $ 1 . 1 million grant as a Sematech Center for Excellence in multilayer metallization.

In parallel with the early development of these Centers, researchers saw opportunities for exploiting the new technologies that were developing and asked the Rensselaer Administration for facilities on-campus to start their own businesses. This was the birth of the "Incubator" program which since 1981 has had forty companies associated with it. Fifty percent of these companies have been formed by Rensselaer faculty, students and staff. The most successfully company was Raster Technologies which grew out of the

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Incubator program and moved to Route 128 in Boston. In terms of economic development of our region, this was a major loss and spurred the Institute to develop 1200 acres of land at a nearby location as a Technology Park. The Rensselaer Technology Park was started in 1983 and today there are in excess of 800 people working in the Park and it become a profit making enterprise in 1987.

These initiatives taken by Rensselaer encouraged New York State to invest $ 30 million, as an interest free loan to Resselaer, to erect the Center for Industrial Innovation. This building now houses the three Centers described earlier as well as new Centers in Automation and Robotics, and the North Eastern Manufacturing Technology Transfer Center.

The Automation and Robotics Center incorporates faculty from both the Department of Mechanical Engineering and that of Electrical and Computer Systems Engineering. In 1988 NASA awarded this Center funding to establish a Center for Intelligent Robotics Systems for Space Exploration (CIRSSE) which is now the core activity. The CIRSSE concentrates on theory essential for developing an autonomous system for assembly, disassembly and repair in Space.

The Center for Advanced Technology in Automation and Robotics was sponsored by New York State and is supported by industry and State funding. The Center concentrates on industrial applications of automation and robotics.

The North Eastern Manufacturing Technology Center (NEMTC) is funded by the National Institute of Standards and Technology (NIST). This Center will deliver advanced manufacturing technology developed at NIST to small and medium sized manufacturers located in the north eastern United States. In addition, it will inform and educate small manufacturers about advanced manufacturing technologies, evaluate the needs of small manufacturers and support work force training.

Thus technology transfer to industry is being achieved primarily through the NEMTC activities and also by:

- students being recruited by industry.
- resident engineers sent to Rensselaer by industry. These engineers have tenures for up to eighteen months, work in research teams and return to their companies.
- patents and licensing.

In the latter case Rensselaer has reviewed its' intellectual property policies, creating a more favorable environment for faculty to seek patents for the products of their research. A more aggressive licensing policy is in the process of being implemented to ensure that technology transfer does occur.

# 3M'S EVALUATION OF RESEARCH AND DEVELOPMENT ACTIVITIES

Geoffry Nicholson*

## 1. Background

In 1963, 3M's Vice President of R&D, Charles W. Walton, realized that the company had reached a size where he could no longer single-handledly stay on top of its R&D activities. To ensure the most productive allocation of 3M's funds, he felt the need for assistance in identifying promising new product and technology programs that could benefit from increased support, and in discovering redundant R&D activities that could result in wasteful duplication of effort.

To accomplish these objectives, Walton initiated technical audits of all major 3M laboratory programs. These audits were patterned after the scientific community's peer review process, in that a committee of laboratory technical directors was appointed to assess laboratories managed by their fellow directors. The feedback to Walton was so useful that, in 1965, he created a new position, Director of Corporate Technical Planning and Coordination (CTP & C) to spearhead technical audits of 3M's R&D programs.

More than 25 years after its initiation, 3M's technical audit system continues to provide regular internal peer reviews of laboratory activities. Through this mechanism, major research programs are assessed, the overall health of laboratories is evaluated, and recommendations on product programs, technology areas and laboratory issues are provided to management.

The atmosphere and attitudes surrounding the audits are recognized as key to their acceptance and success. CTP & C strives for a constructive and supportive approach that will benefit the units being reviewed. Throughout the process, an emphasis is placed on honest and open exchange. In addition, CTP & C tries to remain flexible, allowing modifications in the audit procedure when this will make it more meaningful to an individual laboratory.

Ground rules were established to ensure that the technical audit process

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would not stifle 3M's innovative climate. These emphasized the preservation of individual autonomy: For example, implementation of audit recommendations is not mandatory (i.e., a low rating does not result in the automatic termination of a program). Rather, the audit is used as a tool to help the unit plan and implement programs and allocate resources.

To shelter new efforts, small programs and ideas which are still in early stages, these are exempted from the audit. In addition, auditors are not forced to arrive at a consensus opinion, but are free to make independent program ratings which are averaged later. Thus, the audit system is compatible with a 3M environment which encourages entrepreneurs. However, at the same time, the considerable attention 3M's upper management gives to audit results provides endorsement critical to acceptance of the system.

## 2. Evaluation Procedure

Each R&D unit is reviewed once every two to three years. The date is set months in advance. A typical audit team includes invited members from 3M's laboratory management and senior scientists ranks, management and technical personnel from within the unit being audited. Staff from CTP & C is also invited and the CTP & C director acts as the official auditor.

Several weeks before the audit, a CTP & C manager meets with the laboratory head to select the programs to be evaluated. These include: (1) major new product programs; (2) technology building efforts; (3) process development and cost savings programs; (4) product maintenance work (e.g. incremental product improvements). Audits are conducted as all-day meetings at which members of the laboratory being reviewed make oral presentations, supplemented by written materials which the laboratory has provided prior to the audit.

Rating sheets are used to gather individual auditors' impressions of each R&D program and of the overall laboratory. These forms have evolved over the years as statistical analyses have determined the utility of various questions. With regard to product programs, it has proven valuable for technical factors and business factors to be included. In terms of the laboratory as a whole, factors are included such as organization/planning, staffing, program balance, and coordination/interaction with marketing, manufacturing and other 3M labs.

## 3. Predicting R&D Program Success or Failure

With a data base containing more than 25 years of information, studies have been made of auditors' ratings vs. the actual results of 3M's programs. Results show that the overall probability of program success, obtained by multiplying the probability of technical success by the probability of marketing success, correctly predicts a program's outcome a high percentage of the time.

Follow-up studies of completed programs show that a low audit probability of success rating correlates with failed (i.e., abandoned) programs, while a significantly high audit rating is typical of those that have succeeded in the marketplace.

3M's program success rate has also been analyzed by type of laboratory effort (i.e., maintenance of existing products, related new products, and unrelated new products). Although unrelated programs can have high payoff, they are also more difficult, have a success rate that is less than half that of related programs, and only one-fifth of what maintenance programs achieve.

Ongoing studies of related new product programs have shown that the following factors have a statistically significant impact on R&D success or failure.

- Competitive position of the 3M business unit developing the product;
- 3M product performance vs. competition;
- Degree to which the technology is related to 3M's existing technical base;
- Degree to which the market is related to 3M's existing business base.

The single most critical factor – competitive position – is routinely evaluated by the business unit as part of its strategic plan, where competitive position is defined as the strength of the unit in competing in an industry.

As far as unrelated new product programs are concerned, two factors have been found to be significant in affecting success or failure.

- Uniqueness or "newness to the world" of the product being developed;
- Competitive position (in the closest industry) of the 3M business unit developing the product.

For these programs, where 3M has no competitive position in the industry and where products are not new to the world, a very low success rate is shown. Conversely, when these factors are favorable, programs are not only the most successful but also achieve the largest sales and return the most acceptable profit. Where programs have one favorable and one unfavorable factor, intermediate rates of success are found.

## 4. Some Conclusions

In terms of investment, 3M's technical audit process requires a permanent staff, and demands a time investment by the laboratory being reviewed, as well as the managers/scientists who participate as external auditors.

In terms of positive contributions, 3M's technical audits not only serve as a tool to evaluate the current status of laboratory programs, but also help to predict the ultimate success or failure of an R&D effort. Information on key factors (e.g. the company's strength in the general product area, specific strengths of the product being developed and newness of the product to the firm) provide management with a tool to improve program selection, prioritization, and execution. Overall, the returns from this technical audit approach appear to exceed investment in the process

# R&D ACTIVITY AND ITS PERFORMANCE IN JAPAN

**Kanemi Ban***

## 1. Introduction

The number of patents received by the Japanese almost doubled over the past two decades, while that of other countries declined during the same period. The Japanese were as active in overseas patenting. They sometimes offset what would otherwise have been sharper declines in the patents granted in major industrialized economies. In moving counter to worldwide trends, Japan's R&D performance raised a number of important questions: How should patent data be interpreted? What is characteristic of the Japanese R&D system? What is the government's role in R&D activity? What is the relationship between industrial R&D and university-based research?

As Shinjo [1988] pointed out, governmental R&D expenditures in Japan are much smaller than that of other industrial countries. The governmental share was only 19.6 percent in 1987. It is more than 57 percent in the United States. This fact is contrary to the widely-held view about the large role of MITI (Ministry of International Trade and Industry) in technology policy.

In this paper, first, we investigate how the government and industry have contributed to funding R&D activity in universities. We point out that the share of research funds of universities financed by industrial companies has increased gradually. R&D activities are usually divided among three categories: basic research, applied research, and development. More than 95 percent of the R&D expenditures by companies are allocated to applied research and development. On the other hand, universities have played an important role in basic research. However the increase in the R&D funds contributed by industry to universities has changed the objectives of universities. Second, we show differences in the characteristics of R&D activities between industrial companies and universities. For example, we show that the relationship among productive factors such as capital, labor and material distinguishes the characteristics of R&D activity between companies and universities. Finally, we estimate the value of patent rights in Japan at the aggregate level. We show that the value of patent rights as evaluated by patentees has grown more rapidly than the quantity or count index.

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## 2. Funding R&D Activity in Universities

Figure 2.1 shows the expenditures on R&D in the field of natural science by non-universities from 1971 to 1986. Non-universities include companies and research institutes. Total expenditures have increased by more than 10 percent annually since the late 1960's. The share of expenditures by universities increased from 16 percent in 1971 to 20 percent in 1978, then it declined gradually to 13 percent in 1986. This decline after the late 1970's implies that R&D activity in universities has tended to be behind that of companies.

Figure 2.2 shows the sources of funds for R&D expenditures in universities, as presented in Figure 2.1. Ninety percent of total expenditures has been self-financed. This figure has been very stable since the early 1970's. The remaining 10 percent has been from outside sources. Figure 2.3 shows the origin of funds from outside sources in detail. The funds from government did not increase but declined after the early 1980's. The recent increase in research funding of universities is mainly due to non-governmental sponsorship. Of course, some of the universities are national or public, where the source of funds is the central or local government. If we take this into account, we get Figure 2.4. Even in this figure, we can point out that the share of funding R&D activity by government has declined steadily from 67 percent in 1971 to 62 percent in 1986.

The facts indicate that government funding of R&D activity has declined, even in universities. On the other hand, the strong R&D activity in the private business sector has spilled over into the universities. As a result, the expenditures on R&D by type of activity in universities have changed as follows:

| | Basic Research | Applied Research | Development |
|---|---|---|---|
| 1970 | 75% | 19% | 6% |
| 1986 | 54% | 37% | 9% |

R&D activity in universities has shifted from basic research to applied research.

Figure 2.1 Expenditures on R&D Activity

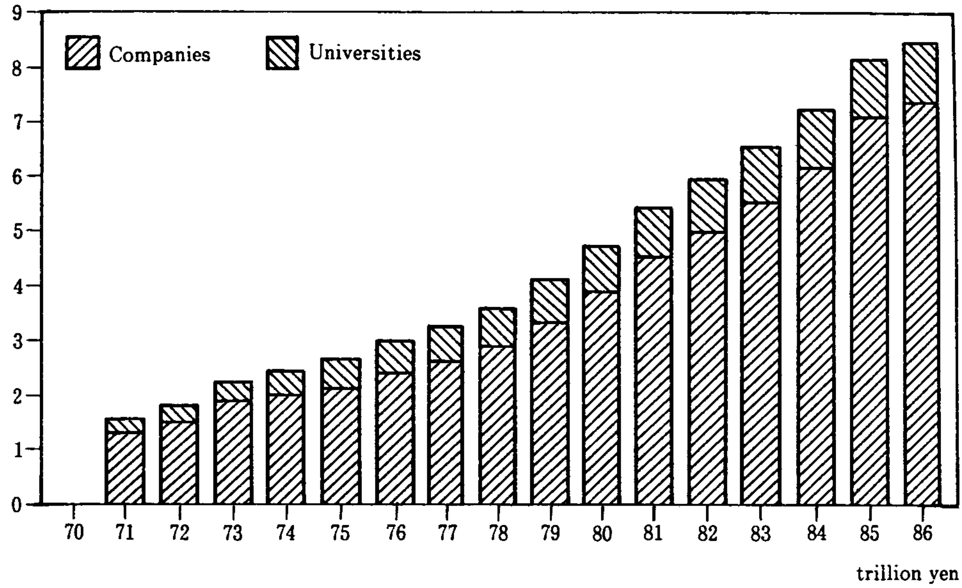



Figure 2.2 Sources of R&D Funds in Universities

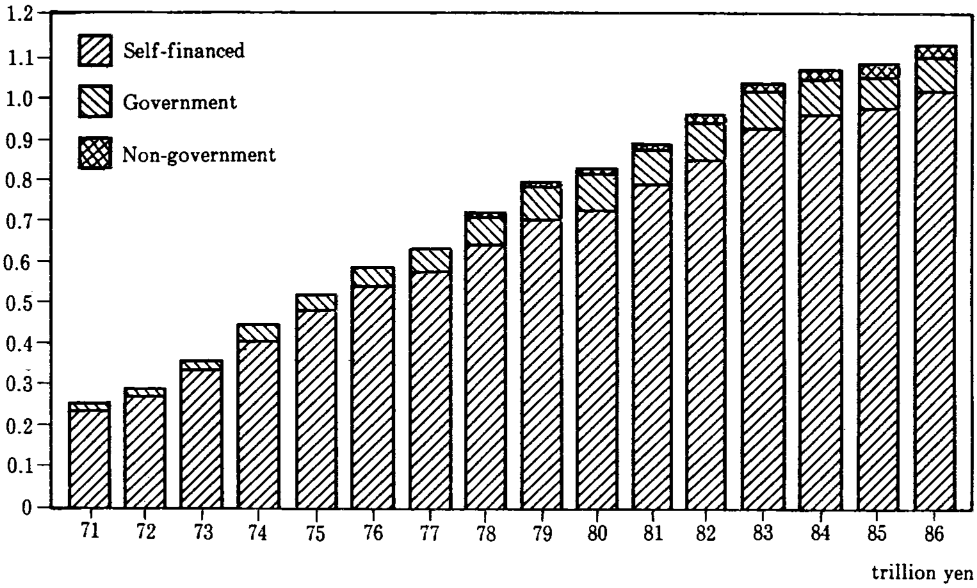


Figure 2.3 R&D Funds from Sources Outside Universities

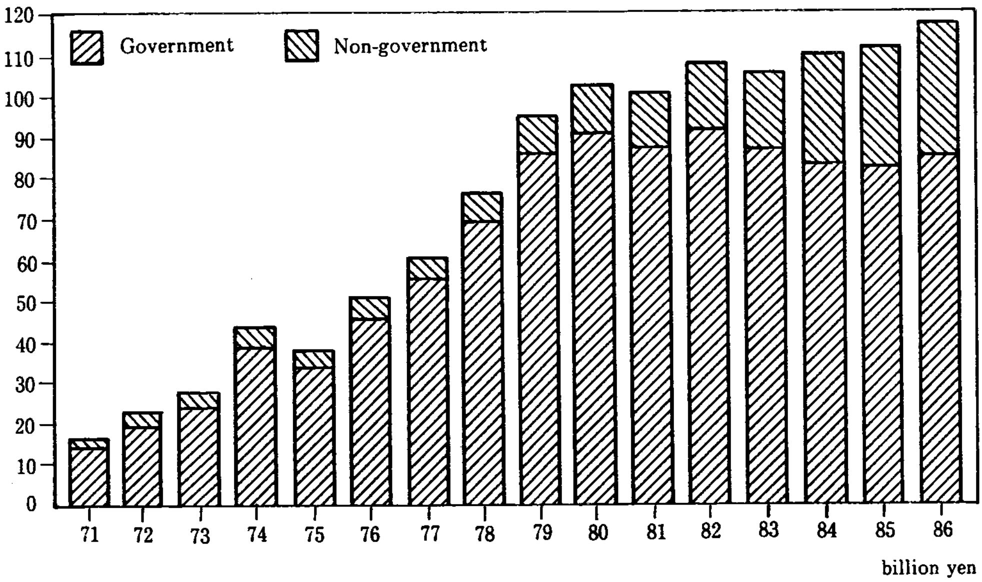
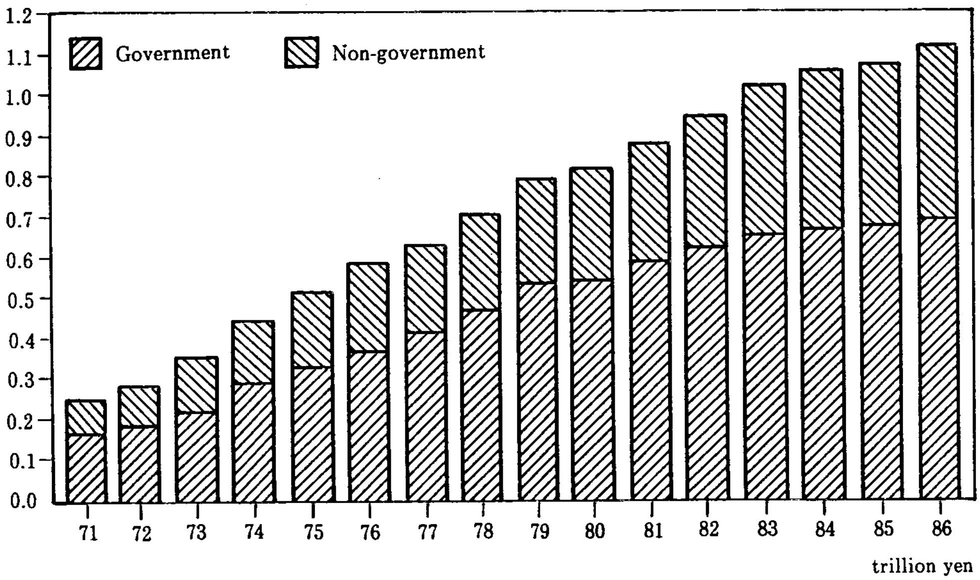



Figure 2.4 Sources of Funds by Type of Orign



## 3. The Difference in R&D Activity between Companies and Universities

In this section, we investigate the substitutability among factors such as capital, labor and material in R&D activities. Recently more attention has been focused on the difference in R&D activities between companies and universities. If there exist some factor differences, we have to take them into account when we allocate research funds.

Table 3.1 shows the cost shares in R&D activity both in companies and universities. First of all, the Table shows that expenditures for labor in universities are relatively higher than for companies. On the other hand, expenditures for material in university are relatively low than that of companies.

Table 3.1 Cost Shares in R&D activity

| | Companies | | | Universities | | |
|---|---|---|---|---|---|---|
| | Capital | Labor | Material | Capital | Labor | Material |
| 70 | 0.219 | 0.397 | 0.384 | 0.194 | 0.638 | 0.167 |
| 71 | 0.194 | 0.424 | 0.382 | 0.190 | 0.640 | 0.170 |
| 72 | 0.174 | 0.453 | 0.373 | 0.169 | 0.646 | 0.185 |
| 73 | 0.179 | 0.453 | 0.369 | 0.159 | 0.659 | 0.182 |
| 74 | 0.139 | 0.502 | 0.358 | 0.153 | 0.673 | 0.174 |
| 75 | 0.132 | 0.518 | 0.350 | 0.158 | 0.674 | 0.167 |
| 76 | 0.116 | 0.519 | 0.365 | 0.157 | 0.658 | 0.185 |
| 77 | 0.121 | 0.509 | 0.370 | 0.158 | 0.660 | 0.182 |
| 78 | 0.125 | 0.498 | 0.378 | 0.176 | 0.637 | 0.187 |
| 79 | 0.137 | 0.479 | 0.384 | 0.184 | 0.626 | 0.189 |
| 80 | 0.151 | 0.462 | 0.387 | 0.179 | 0.636 | 0.185 |
| 81 | 0.160 | 0.442 | 0.398 | 0.176 | 0.629 | 0.195 |
| 82 | 0.159 | 0.433 | 0.407 | 0.173 | 0.630 | 0.198 |
| 83 | 0.154 | 0.435 | 0.410 | 0.170 | 0.628 | 0.202 |
| 84 | 0.155 | 0.421 | 0.424 | 0.163 | 0.642 | 0.194 |
| 85 | 0.165 | 0.407 | 0.429 | 0.159 | 0.643 | 0.198 |
| 86 | 0.158 | 0.416 | 0.426 | 0.140 | 0.665 | 0.195 |

We assume that there exists a twice differentiable aggregate production function relating the flow of R&D output to three inputs: capital (K), labor (L), and all other intermediate materials (M). Further, we assume constant returns to scale in R&D activity. Corresponding to such a production function, there exists a cost function which reflects the production technology. This is known as the duality relation between prices and quantities. In its general form, we write this cost function as:

$C = f\ (R, P_K, P_L, P_M,)$

$C$ : total cost
$R$ : output of R&D activity
$P_K$ : input price of K
$P_L$ : input price of L
$P_M$ : input price of M

In order to estimate this function, we have to employ a specific function for C. We use the translog approximation to this cost function with symmetry and constant returns to scale imposed as:

$$\ln C = \alpha_0 + \ln R + \sum_{i=K,L,M} \alpha_1 \ln P_i + \frac{1}{2} \sum_{i,j=K,L,M} \sum \beta_{ij} \ln P_i \ln P_j + \sum_{i=K,L,M} \mu_i T \ln P_i \quad ,$$

where T is time trend and $\mu_i$ presents factor augmenting technical charge bias. Linear homogeneity in prices imposes the following restrictions.

$$\alpha_K + \alpha_L + \alpha_M = 1$$
$$\beta_{ij} = \beta_{ji}$$
$$\beta_{KK} + \beta_{KL} + \beta_{KM} = 0$$
$$\beta_{KL} + \beta_{LL} + \beta_{LM} = 0$$
$$\beta_{KM} + \beta_{ML} + \beta_{MM} = 0$$
$$\mu_K + \mu_L + \mu_M = 0$$

Assuming the perfect competition in the factor markets, we treat input prices as fixed. Given the level of R&D output, cost minimizing input demand functions are derived as follows:

$$\partial \ln C / \partial \ln P_i = S_i = \alpha_i + \sum_{i=K,L,M} \beta_{ij} \ln P_j + \mu_i T$$

$$i = K, L, M$$

According to Shephard's lemma, $S_i$ is the cost shares of inputs in the total cost of producing R. Then we can reduce the following estimable equations by dropping the materials share equations.

$$S_K = \alpha_K + \beta_{KK} \ln (P_K/P_M) + \beta_{KL} \ln (P_L/P_M) + \mu_K T$$
$$S_L = \alpha_L + \beta_{KL} \ln (P_K/P_M) + \beta_{LL} \ln (P_L/P_M) + \mu_L T$$

With the translog cost function, we can derive the Allen partial elasticities of substitution between input i and j as,

$$\sigma_{ij} = (\beta_{ij} + S_i S_j) / S_i S_j .$$

The price elasticities of demand for factors of R&D activity are defined by

$$E_{ij} = S_{ij} \sigma_{ij} .$$

Table 3.2 shows the estimates by Iterative Seemingly Unrelated methods over the period from 1970 through 1986. The parameters of factors augmenting technical progress are not significant in the case of universities. A cost function is well behaved if it is concave in input prices and if its input demand functions are strictly positive. These conditions are satisfied at each observation. According to the results, the R&D activity in companies has a capital-using technical change bias, and a labor-saving technical change bias. In the case of universities, we neither observe labor nor capital-using technical change biases.

Table 3.3 shows the elasticities of substitution. The figures are stable over the sample periods. Several important conclusions emerge from the table. In the case of companies, capital and labor are substantially complementary. This implies that higher labor costs will dampen the demand for capital. On the other hand, capital and labor are substitutable in universities. This implies that higher labor costs will increase the demand for capital. Capital and material are substitutable in companies, while they are complementary in universities. Labor and material are substitutable both in companies and universities.

We briefly note some policy implications of these empirical results. Investment tax credits and accelerated depreciation allowances to reduce the cost of capital services generate increased demand for labor in companies, while they reduce demand for labor in universities.

In the last section, it was shown that most of the R&D activities in universities have been financed by the Japanese government. It was also shown that the government share of university funding has declined. In this section, the method was discussed through which this decline in share of government funding for universities has been accomplished. That is, the government subsidized expenditures for equipment, which reduced costs because of the substitutability between capital and labor. Since labor costs are relatively high in universities, this reduction was the most efficient means to cut expenditures. Overall, according to the analyses of these sections, the objective of the Japanese government was to minimize their expenditures for R&D activities.

We conclude by noting the price elasticities of factor demand in Table 3.4.

The price elasticities of material are −0.6 or −0.7, which are relatively higher than that of capital and labor, −3 or −0.5, both in companies and universities.

Table 3.2 Parameter Estimates *

| | Companies | | Universities | |
|---|---|---|---|---|
| $\alpha_K$ | 0.0677 | (1.45) | 0.1609 | (41.4) |
| $\alpha_L$ | 0.6345 | (8.93) | 0.6489 | (159.) |
| $\beta_{KK}$ | 0.1803 | (2.06) | 0.0642 | (2.84) |
| $\beta_{KL}$ | −0.3050 | (2.38) | −0.0010 | (0.04) |
| $\beta_{LL}$ | 0.4333 | (2.19) | −0.0488 | (1.93) |
| $\mu_K$ | 0.0084 | (1.87) | | |
| $\mu_L$ | −0.0173 | (2.51) | | |

* The figures in parentheses are asymptotic t-ratios.

Table 3.3 Elasticities of Substitutions

| | Companies | | | Universities | | |
|---|---|---|---|---|---|---|
| | $\sigma_{KL}$ | $\sigma_{LM}$ | $\sigma_{KM}$ | $\sigma_{LK}$ | $\sigma_{LM}$ | $\sigma_{KM}$ |
| 70 | −2.510 | 0.159 | 2.481 | 0.992 | 1.466 | −0.940 |
| 71 | −2.703 | 0.207 | 2.680 | 0.992 | 1.457 | −0.955 |
| 72 | −2.866 | 0.241 | 2.918 | 0.991 | 1.417 | −1.020 |
| 73 | −2.773 | 0.232 | 2.894 | 0.990 | 1.415 | −1.187 |
| 74 | −3.355 | 0.287 | 3.497 | 0.990 | 1.426 | −1.369 |
| 75 | −3.469 | 0.293 | 3.704 | 0.990 | 1.441 | −1.386 |
| 76 | −4.062 | 0.323 | 3.948 | 0.990 | 1.410 | −1.178 |
| 77 | −3.941 | 0.318 | 3.779 | 0.990 | 1.415 | −1.200 |
| 78 | −3.909 | 0.317 | 3.645 | 0.991 | 1.418 | −0.918 |
| 79 | −3.637 | 0.302 | 3.364 | 0.991 | 1.421 | −0.805 |
| 80 | −3.379 | 0.283 | 3.135 | 0.991 | 1.423 | −0.905 |
| 81 | −3.305 | 0.270 | 2.957 | 0.991 | 1.407 | −0.846 |
| 82 | −3.419 | 0.273 | 2.921 | 0.991 | 1.400 | −0.853 |
| 83 | −3.539 | 0.282 | 2.968 | 0.990 | 1.393 | −0.839 |
| 84 | −3.674 | 0.281 | 2.894 | 0.990 | 1.399 | −0.989 |
| 85 | −3.558 | 0.264 | 2.767 | 0.990 | 1.391 | −1.011 |
| 86 | −3.646 | 0.277 | 2.853 | 0.989 | 1.384 | −1.316 |

Table 3.4 Price Elasticities

| | Companies | | | Universities | | |
|---|---|---|---|---|---|---|
| | $\varepsilon_{KK}$ | $\varepsilon_{LL}$ | $\varepsilon_{MM}$ | $\varepsilon_{KK}$ | $\varepsilon_{LL}$ | $\varepsilon_{MM}$ |
| 70 | −0.042 | −0.489 | −0.606 | −0.475 | −0.438 | −0.753 |
| 71 | −0.122 | −0.446 | −0.609 | −0.472 | −0.436 | −0.751 |
| 72 | −0.209 | −0.410 | −0.617 | −0.451 | −0.430 | −0.743 |
| 73 | −0.189 | −0.410 | −0.622 | −0.437 | −0.415 | −0.745 |
| 74 | −0.433 | −0.365 | −0.632 | −0.428 | −0.400 | −0.749 |
| 75 | −0.501 | −0.354 | −0.640 | −0.436 | −0.398 | −0.753 |
| 76 | −0.671 | −0.354 | −0.626 | −0.434 | −0.416 | −0.743 |
| 77 | −0.608 | −0.360 | −0.620 | −0.436 | −0.414 | −0.745 |
| 78 | −0.569 | −0.368 | −0.613 | −0.459 | −0.440 | −0.741 |
| 79 | −0.450 | −0.384 | −0.607 | −0.468 | −0.452 | −0.740 |
| 80 | −0.347 | −0.400 | −0.603 | −0.462 | −0.441 | −0.743 |
| 81 | −0.286 | −0.422 | −0.593 | −0.459 | −0.448 | −0.737 |
| 82 | −0.291 | −0.433 | −0.584 | −0.455 | −0.448 | −0.735 |
| 83 | −0.323 | −0.431 | −0.581 | −0.453 | −0.450 | −0.732 |
| 84 | −0.318 | −0.451 | −0.567 | −0.444 | −0.434 | −0.737 |
| 85 | −0.261 | −0.472 | −0.563 | −0.437 | −0.433 | −0.734 |
| 86 | −0.300 | −0.458 | −0.565 | −0.401 | −0.408 | −0.736 |

## 4. Estimates of Patent Value in Japan and R&D Performance

In this section, we attempt to estimate the value of patent rights in Japan, and provide a quality index for patents. It has been pointed out that the number of patents in Japan has increased rapidly, while it has declined in European countries. Figure 4.1 shows the number of patent application in each country. Okimoto and Saxsonhouse [1987] point out that the slight increase in patenting in the United States would have turned into a decline if approvals for Japanese nationals had been excluded from the U.S. patent total. Recently, the share of patents approved for Japanese nationals reached over 20 percent in the United States. The performance of R&D activity in Japan has raised a number of important questions related to Japan's high activity patenting. How should the number of patents be interpreted? Schankerman and Pakes [1986] show that the total value or quality of patents in the United Kingdom, France and Germany has increased substantially late 1960's, even though the number of patents declined during the same period. This result implies that we have to take the quality of patents into account to evaluate the performance of R&D activities for a country.

Table 4.1 shows the number of application filed, examined, granted and registered. The number of applications appears high, but many are not ordered for examination. For example, 35 percent of applications in 1979 were not ordered for examination. Applicants have to order examination by the patent office within seven years. Table 4.2 shows the number of orders for examination in 1979. The long time to process patent applications, according to Table 4.2, is partly due to the applicant's decision to delay examination.

Figure 4.1 The Number of Applications

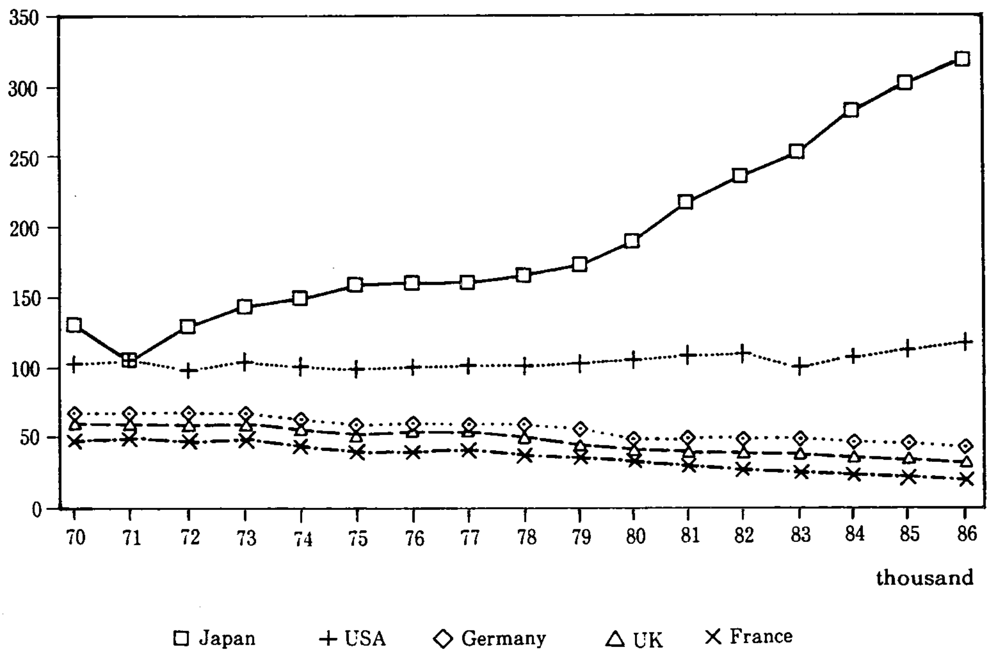


Table 4.1 The Number of Applications/Examinations/Granted/Registrations

| | Application | Examination | Granted | Registration |
|---|---|---|---|---|
| 65 | 81923 | 59775 | 27150 | 26905 |
| 66 | 86046 | 52246 | 24980 | 26315 |
| 67 | 85364 | 56288 | 28416 | 20773 |
| 68 | 96710 | 65711 | 36239 | 27972 |
| 69 | 105586 | 65737 | 35419 | 27657 |
| 70 | 130831 | 69871 | 38166 | 30879 |
| 71 | 105785 | 80493 | 48007 | 36447 |
| 72 | 130400 | 84281 | 45834 | 41454 |
| 73 | 144814 | 78844 | 45149 | 42328 |
| 74 | 149319 | 86441 | 43533 | 39626 |
| 75 | 159821 | 80942 | 42997 | 46728 |
| 76 | 161016 | 85323 | 48931 | 40317 |
| 77 | 161006 | 98533 | 51626 | 52608 |
| 78 | 166092 | 83988 | 37272 | 45504 |
| 79 | 174569 | 85524 | 47380 | 44104 |
| 80 | 191020 | 97592 | 56719 | 46106 |
| 81 | 218261 | 96171 | 53835 | 50904 |
| 82 | 237514 | 99607 | 53390 | 50601 |
| 83 | 254956 | 96778 | 53155 | 54701 |
| 84 | 284767 | 96746 | 53362 | 61800 |
| 85 | 302995 | 102016 | 55978 | 50100 |
| 86 | 320089 | 113754 | 61479 | 59900 |
| 87 | 341095 | 112128 | 61015 | 62400 |

Table 4.2 The Number of Orders for Examination by Applicants in 1979

| | Examination |
|---|---|
| 79 | 24156 |
| 80 | 7847 |
| 81 | 10584 |
| 82 | 10441 |
| 83 | 12478 |
| 84 | 12654 |
| 85 | 10774 |
| 86 | 25448 |
| 87 | 120 |

Much research involving patent variables employs simple counts of patents. The patent count measure has served both as an indicator of the value of the output of patented ideas and as an indicator of the value of proprietary rights created by patent laws. However, the average value of patented inventions may differ among groups of patentees or over time periods. If so, the difference in the number of patents among groups or time periods will provide systematically biased estimates of differences in their value. Moreover some case studies and their econometric evidence indicate that the distribution of the value of patented ideas is very disperse and highly skewed. This implies that patent count data have much noise as a measure of the value of patented ideas.

The principal objective of this section is to estimate patent rights in Japan. The value of patent is in general unobserved, because patent rights are seldom marketed. In this section, we use the method proposed by Schankerman and Pakes [1986]. In most countries, patentees have to pay an annual renewal fee in order to keep their patents in force. If it is assumed that agents make renewal decisions based on the value of patent rights, then data on patent renewals and renewal fee schedules contain information on the distribution of the value of patent rights. Table 4.3 shows renewal fees for keeping patent rights.

Table 4.3 Renewal Fees for Keeping Patent Rights

| | |
|---|---|
| 1 - 3 years | 10,300 yen |
| 4 - 6 | 16,000 |
| 7 - 9 | 32,000 |
| 10 - 12 | 64,000 |
| 13 - 15 | 128,000 |

Schankerman and Pakes propose the following model to estimate the value of patent rights.

Each patentee chooses the life-span of the patent, T, to maximize the discounted value of net returns.

$$\max_{T} \; V(T) = \sum_{t=1}^{T} (R_{tj} - C_{tj}) \, (1 + r)^{-t}$$

$R_{tj}$ : revenue from the patent in cohort j at age t

$C_{tj}$ : renewal fee for holding the patent in cohort j at age t

r : discount rate

We assume that the sequence of

$$R_{tj} = R_{oj} \, \Pi^{t}_{\tau=1} \, d_{\tau j}$$

$R_{pj}$ : intial returns

$d_{\tau j}$ : rate of decay

is supposed to be known with certainty when the patent is applied for. If the sequence of $(R_{tj} - C_{tj})$ is non-increasing in t, the optimal life-spant is the first age of at which

$$R_{tj} < C_{tj}$$

If no such T exists, then T is 15 in Japan. This means that the condition for renewal of the patent age t is that the annual returns at least cover the cost of renewal,

$$R_{tj} \geqq C_{tj}$$

Since the renewal fees are non-decreasing in age, a condition which insures that net revenues are non-increasing is that the sequence of $R_{tj}$ is non-increasing, that is, that the returns to holding a patent decay over time.

$R_{tj}$ reflects the intial returns $R_{0j}$ and the rate of decay $d_{tj}$ if and only if

$$R_{0j} \geqq C_{tj}\ \Pi^{t}_{\tau=1}\ d^{-1}_{\tau=1}$$

it will be renewed at age t. Let $f(R_{0j}\ ;\ \theta_j)$ and $F(R_{0j}\ ;\ \theta_j)$ be the density and distribution function of intial revenues, where $\theta_j$ denotes a vector of parameters. Then the proportions of patients in cohort j renewed at age t is,

$$P_{tj} = \int_{Z_{tj}} f(R_{0j}\ ;\ \theta_j)\ dR_{0j} = 1 - F(Z_{tj}\ ;\ \theta_j)$$

$$Z_{tj} = C_{tj}\ \Pi^{t}_{\tau=1}\ d^{-1}_{\tau=1}$$

Here the distribution of initial revenues, $f(R_{0j}\ ;\ \theta_j)$ is supposed to be log normal. That is, (wave, not minussign)

$$r_{0j} = \log R_{0j} \sim N(\mu_j,\ \sigma^2_j).$$

A patent is renewed if and only if

$$\frac{r_{0j} - \mu_j}{\sigma_j} \geqq \frac{c_{tj} - \mu_j - \sum_{\tau=1}^{t} \ln d_{\tau j}}{\sigma_j}$$

Noting that $(r_{0j} - \mu_j) / \sigma_j$ is a standard normal distribution, the proportions of patents in cohort j which have dropped out by age t is,

$$1 - P_{tj} = \Phi\left( \frac{c_{tj} - \mu_j - \sum_{\tau=1}^{t} \ln d_{\tau j}}{\sigma_j} \right)$$

where Φ is the standard normal distribution function. This implies that

$$y_{tj} = \Phi^{-1}(1 - P_{tj}) = \frac{c_{tj} - \mu_j - \sum_{\tau=1}^{t} \ln d_{\tau j}}{\sigma_j}$$

We assume that $\sigma_j$ and $d_{\tau j}$ are constant over the sample period.

We estimate the model over the period from 1972 through 1982. Table 4.4 shows the estimated results.

Table 4.4 The Parameter Estimates of the Patent Renewal Model

| | | |
|---|---|---|
| $\mu_{72}$ 11.140 (8.70) | $\mu_{73}$ 11.346 (8.46) | $\mu_{74}$ 11.326 (8.79) |
| $\mu_{75}$ 11.704 (7.87) | $\mu_{76}$ 12.153 (6.01) | $\mu_{77}$ 12.253 (5.74) |
| $\mu_{78}$ 12.692 (3.88) | $\mu_{79}$ 12.957 (2.80) | $\mu_{80}$ 13.280 (1.44) |

$\mu_{81} = \mu_{82} = 13.690$ (66.934)

d 0.8729 (5.68) $\sigma$ 3.200 (2.51)

adj $R^2 = 0.955$

The figures in parantheses are asymptotic t-vaive.

Table 4.5 Estimated Distribution of Patent Value (1985 prices)

| | median<br>$10^4$ yen | mean<br>$10^4$ yen | total<br>$10^8$ yen |
|---|---|---|---|
| 72 | 6.9 | 1152 | 4776 |
| 73 | 8.4 | 1416 | 5994 |
| 74 | 8.3 | 1388 | 5500 |
| 75 | 12.1 | 2026 | 9467 |
| 76 | 19.0 | 3174 | 12797 |
| 77 | 21.0 | 3508 | 18455 |
| 78 | 32.5 | 5441 | 24759 |
| 79 | 42.3 | 7091 | 31274 |
| 80 | 58.5 | 9795 | 45161 |
| 81 | 88.2 | 14760 | 75134 |
| 82 | 88.2 | 14760 | 74687 |

Table 4.5 shows the distribution of the value of patents rights for each cohort. The most prominent feature of the distribution is its sharp skewness. The median value of patent rights is 882,000 yen in 1982, while its average is 14,760,000 yen. This result coincides with that of Schankerman and Pakes for the United Kingdom, France and Germany to some extent. However, the degree of skewness of the distribution for Japan is more than 100, while that for European countries is around 3 or 4. This implies that there is a dense concentration of patents rights with very little economic value. Even though

the number of patent applications granted in Japan is tremendously large as compared with that of other countries, most of them are worth little. Only 10 percent of all patent rights are worth more than 10 million yen.

We also have to point out that the total value of patent rights has grown rapidly despite the large amount of low quality patents. Rapid growth in value is mainly due to high-value R&D activities. However, that the growth rate of patent values is higher than that of R&D investment might imply that the rate of return from R&D is relatively high in Japan, or that the Japanese are beginning to put some more emphasis on knowledge-based assets.

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# THE INTERRELATION BETWEEN INVESTMENT IN S&T AND ECONOMIC PERFORMANCE

**Ken-Ichi Inada***

In this paper, the interrelationship between investment in science and technology and economic performance will be discussed.

The most important factor that promotes economic growth is technological progress. This finding has been confirmed in empirical research by several economists. Based on the recognition of this fact, both national and local governments, as well as private enterprises in all advanced industrial countries have come to the common understanding that promotion of research programs for technological progress is essential for sustained growth of their economies. In fact, without constant progress in technology, that is, with mere quantitative expansion of capital goods of the same qualities and capabilities, and with a labor force of the same qualities, labor productivity will sooner or later reach a ceiling, and the economy would be unable to continue its course of growth. For these reasons, funds set aside for improving the quality of capital goods and the labor force, as well as those set aside for the purpose of aiming directly at economic expansion, should be viewed as part of investment.

Some comments, therefore, on the type of science and technology investment mentioned above are necessary. First, in the case of investment in basic research, this type of research is aimed mainly at discovering new phenomena and analysis of the mechanisms of already or newly observed phenomena. The outcomes of this type of research are valuable, since they signify a broadening of human knowledge. They do, however, have little immediate economic significance. To link the outcomes of basic research with the economic well-being of society, another type of research, namely, developmental research is indispensable. However, even this type of research is not sufficient for economic development. That is, any superior technology developed by this type of research is in itself like cakes painted on a canvas. What necessary element then, is lacking for economic development?

To link technological progress with economic development, it is necessary that capital goods embodying the developed technologies are actually produced, and labor, educated or trained for operation of the improved capital goods, is supplied. This is because new technology is usually utilized in actual production of commodities or supply of services in the forms of

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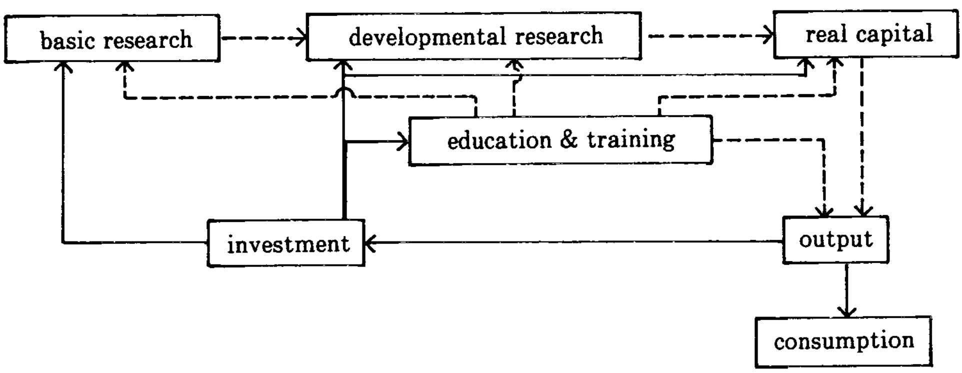
new capital goods. The cases in which the methods used in producing old type capital goods are improved are rather rare. Moreover, even in those cases, education and training of the labor force is necessary. At any rate, without new capital goods and a labor force trained for their production, new technology cannot be utilized to its full potential.

The economy itself is also required to be sound in order for it to grow steadily, that is, both the economic growth rate, and the savings ratio must be maintained at certain levels. Without these factors, new capital goods could not be produced and a labor force with the required skills could not be made available, nor would the funds for them be supplied. In fact, without the funds supplied by savings, it would be impossible to raise money even for S&T investment. From the other side, if the economy is stagnant, it cannot afford to invest, neither on research nor on real capital nor on training of a labor force. The economy cannot grow, and is caught in a vicious circle. In such a case, the most important policy for the government is to help the economy by enacting an adequate macro-economic policy, especially oriented towards growth.

The pattern of an economic cycle especially emphasizing research investment, is shown in Fig. A.




real line ——————> show a flow of money

dotted line - - - - - -> show a flow of information and/or service

Fig. A

A similar diagram of an economic cycle showing the flow of goods and services (including research service and its products, i.e. information and knowledge) among economic entities, such as households, governments, and private firms, can be also described.

So far we have described the general pattern of an economic cycle, including investment in research activities. Now we will briefly describe the pattern for a concrete economy, namely, the Japanese economy. It seems that Japan has not placed emphasis on investment in basic research. In the past, private firms in Japan have transferred or bought the outcomes of this kind of research, mainly from the United States. Since this kind of research does not lead directly to profit-yielding production, the prices for transfering or buying it are generally not very high.

On the other hand, Japan has put strong emphasis on investment in developmental research, education, training and real capital goods. The funds supplied for these were accumulated through the notably high Japanese saving ratio (higher than 20%). From the standpoint of Japanese economic interests, this strategy was economically rational, provided the fountain of basic research in the world did not dry up. In fact, the outcomes of basic research spurted during the 60's and 70's. To utilize these research results for economically profitable production, Japanese private firms invested mainly in developmental research, in capital goods embodying these developed technologies, and in education and training to adjust to them. Since the Japanese economy had been growing smoothly at an extraordinarily high rate during the above mentioned periods and the succeeding years, there was enough money for investment. Japan has not actually experienced an economic phase of shortage in investment funds for developmental research, capital goods or education since 1960. The situation, however, has been changing since 1980. Japan has been criticized as being a free rider on common human assets. Moreover, the inventory of seeds for technological progress is going out of stock. Thus, a cry has arisen for the necessity of Japan to promote its own basic research.

Compared to the Japanese economy, the U.S. economy has been experiencing economic stagnation during the 80's. As is universally known, its recent seemingly good condition is haunted by deficits. It seems apparent that this situation cannot be maintained much longer. If the U.S. does not stand on its own feet soon, the day of liquidation will come sooner or later. The elevation of the saving ratio (5%) is the most urgent matter for macro-economic policy. The U.S. economy must raise funds from its own sources to invest in developmental research as well as in real capital goods and labor embodying the developed technologies. The theme of this conference is S&T investment policy. While these policy matters are not unimportant, as far as economic performance is concerned, the most urgent policy matter is that of growth. As has been historically observed, S&T investment policy works fully only for an actively growing economy. The American economy must have been such an economy during the 1960's.

Contrary to the objectives of the conference, I would emphasize the impact of economic performance on S&T investment, as far as the U.S economy is concerned. As for the Japanese economy, however, investment in S&T, especially basic research, must be accelerated. Otherwise, future prospects for long run sustained growth are bleak.

# BIOTECHNOLOGY IN JAPAN: ITS PAST AND FUTURE

**Shukuo Kinoshita***

## (1) Impact of r-DNA Technology.

The rapid advancement of basic and applied research in recombinant DNA techniques in the United States had a great impact upon Japanese biotechnology. The news that Genentech Corporation had succeeded in the production of a human growth hormone using *E. coli* struck like lightning in Japan. Within a few years, almost all biological research institutes, governmental and private, rushed to expand research activity in this new technique. This is still continuing, and many companies which were indifferent to biotechnology are now hurrying to catch up in this new technology by setting up biotechnology research groups in their laboratories.

## (2) Biotechnological Activity in Japan;

Except for these newcomers, biological companies (fermentation) in Japan can be divided into three categories depending upon their products. They are industrial, food and beverages, and pharmaceutical. The market value of these products is about 100 billion U.S. dollars per year. About 40% of it is in the sale of alcoholic beverages, beer, whisky, sake, and so on. Among them, sake brewing technology has much to do with the basis of biotechnology because sake is made by very complex and integrated activities among mold yeast and bacteria. It is surprising that a method for producing sake was established before the existence of microbes was known. Even in the light of modern knowledge of microbiology, the process is quite theoretically-sound and appropriate.

Although the number of sake breweries is decreasing, more than 2000 breweries are still in operation all over Japan. Due to the sake brewing industry, universities kept up their supply of graduates with microbiology backgrounds. During these years, a large pool of personnel for microbiology research was formed.

Concerning the antibiotic industries, they were born after World War II in 1946 when Japan was an occupied country. The first antibiotic was penicillin which was brought from the United States due to occupational

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policy. Many other antibiotics were introduced one after another mostly from the United States, and this industry became successful very quickly.

Basic research for new antibiotics and anticancer drugs proceeded energetically even under the very poor laboratory conditions at that time. The fact that in the 1960's the number of discoveries of new compounds exceeded that in other advanced countries was seen as a tremendous accomplishment. This demonstrates that microbiology research as applied to infectious diseases has a firm basis.

A very unique fermentation industry was born in Japan in 1957. It is "amino acid fermentation". Amino acids are well known as the key building blocks of proteins in all living things on the earth. The man who first noted, in 1908, the commercial importance of an amino acid - glutamic acid - was Prof. K. Ikeda. He found that the monosodium salt of glutamic acid strongly enriched the flavor of food. Through his discovery, monosodium glutamate (MSG) became a world commodity, and many factories for its production were built worldwide. Glutamate was obtained by decomposing plant proteins such as soybeans and wheat gluten.

In contrast, the new method of amino acid fermentation stems from an entirely different principle. Its principle is in biological synthesis and not in chemical decomposition of plant protein. The idea is to utilize the infinite protein synthesizing activity of a bacterium. The method is called the "metabolic control process" because the protein synthesizing activity is controlled and manipulated to accumulate a specific amino acid in the broth. Carbohydrates and ammonia are the main substrates, and, therefore, production costs are very reasonable. The chemical configuration of amino acid produced is, without exception, natural L-form, thus eliminating the hazardous D-L resolution process. The process has many economical merits. It is now thought to be the best method for amino acid production. Since the appearance of this new method, the demand for amino acids (about 20 kinds) expanded not only for food, but for medical use, and even in animal nutrition.

Recent world production is about 60 - 65 $\times 10^4$ metric tonnage (MT). If this amount of amino acid was produced from plant protein, considerable amounts of crop, about $10^8$ MT, and in the case of soybean, $3 - 4 \times 10^7$ MT, would have to be sacrificed for the purpose.

Japan has another unique fermentation technology, which is almost a monopoly in the world. It is called "nucleotide fermentation" by which a variety of nucleic acid related compounds are produced. Among them, inosinic acid and guanylic acid are very potent flavor enhancers when used in combination with MSG. Because nucleotides are the main component of the heredity entities of genes, that some of their related compounds contribute to enhancing food flavour is very suggestive.

The above is a brief history of the fermentation industry before the appearance of the DNA-recombinant process. Although Japanese biological researchers, until ten years ago, were somewhat indifferent to rapid advancement of the new technology, the basis for the new technology was rich and well-cultivated.

### (3) The Role of BIDEC

Apart from changes in individual research organizations, an existing organization "Association of Industrial Fermentation" was reformed into a new organization called the "Biotechnology Development Center" (BIDEC) in 1982. Member companies increased immediately about two times. The reorganization was very successful. One important objective of BIDEC is to move internationally with open exchange of information and discussion. An international biotechnological symposium and fair was held twice (1986 and 1988) in Tokyo and both were very successful. As a private organization, BIDEC is willing to talk with any country on environmental and intellectual property problems. *BIDEC News* is published and circulated internationally, describing highlights in Japanese biotechnology. The hope is that BIDEC can contribute to solving biotechnology related problems which might occur in the future.

### (4) Future Prospects

Nine years have passed since the Japanese government set guidelines and research in r-DNA started. The learning and practicing stage is over, and the application stage is now the target. Many kinds of monoclonal antibodies are produced and marketed for diagnostic tests. This field is the most rapidly growing and advanced one.

Larger molecular proteins which are biologically active are also produced, and many of them are under clinical testing. A protein engineering research institute was established in Osaka City with supporting funds from many companies, Ocean-bio Company was the first to start basic research on marine biology. In the plant and agricultural field, a variety of research is going on, some of which was successful in propagating virus free shoots of potato and lily.

In conclusion, very energetic research in biotechnology is now proceeding in a variety of directions, but biological phenomena are complex and results are difficult to achieve. International cooperative work and information exchange appears necessary to accelerate success.