No. 712

Appropriation of Returns from Technological Assets and the Values of Patents and R&D in Japanese High-Tech Firms

by

Shoko Haneda and Hiroyuki Odagiri

February 1997

Appropriation of Returns from Technological Assets and the Values of Patents and R&D in Japanese High-Tech Firms

Shoko Haneda* and Hiroyuki Odagiri**

February 1997

*	Doctoral Program in Policy and Planning Sciences University of Tsukuba
**	Institute of Policy and Planning Sciences University of Tsukuba
Correspondence to:	Shoko Haneda Doctoral Program in Policy and Planning Sciences University of Tsukuba Tsukuba, Ibaraki 305, Japan e-mail: shaneda@shako.sk.tsukuba.ac.jp

JEL Classification:	O32, O34, G12
Key Words:	Patents, R&D stock, Tobin's q

An early version of this paper was presented at the workshops of Industrial Organization Study Group and of the University of Tsukuba, and we thank A. Matsui, Y. Miwa, T. Shiba, R. Wakasugi, and other participants for comments.

ABSTRACT

This paper investigates how much technological assets contribute to the value of the firm using the sample of 90 Japanese firms in pharmaceutical, chemical, and electrical equipment industries. We use the firm's R&D expenditures and the number of patents (in stock) as the measures of its technological assets and show that the relative usefulness of these two measures varies across industries. Particularly, Tobin's q is positively related to the technological assets most strongly in the pharmaceutical industry. It is also most sensitive to the level of patent stock, coinciding with the view that drug patents are more effective than other patents as a means of appropriating returns from innovation. The communications equipment industry was also characterized by its q's dependence on patent stock. In addition, the industry was sensitive to the level of net R&D investment in the most recent year, presumably because of the rapid technological progress.

1. Introduction

In the firm, tangible assets alone are insufficient to create values: intangible assets are also essential. This fact has been recognized by many writers, beginning with Schumpeter (1942), who stressed the role of innovation and entrepreneurship, and Penrose (1959), who regarded the firm as a collection of physical and human resources that include entrepreneurial and managerial competencies. An increasing number of researchers now agree that intangible assets are the sources of organizational and technological capabilities and competencies, which give the firm its unique competitive advantages (Teece, Pisano, and Shuen, 1992).[1]

This paper purports to investigate how much intangible assets, technological assets in particular, contribute to the value of the firm. The neoclassical theory predicts that Tobin's q (the market value of the firm as a ratio to the replacement value of its tangible assets) is unity in the long run provided there is no adjustment cost in investment and no barrier to entry. Yet, if a firm is endowed with more technological and other intangible assets, the capital market will evaluate this firm as more valuable than the other firm with the same amount of tangible assets; hence, its q must be larger. The first purpose of this paper is to confirm this relationship using the sample of 90 Japanese firms in pharmaceutical, chemical, and electrical equipment industries.

The second purpose pertains to the measurement of technological assets. More precisely, the question is how investors infer the level of technological capability of each firm when they make their portfolio decisions. The most common measures are the firm's R&D expenditures and the number of patents (in flow or stock), and we wish to know their relative usefulness in predicting the market value of the firm. This relative usefulness may vary across industries in an important fashion.

As is well known, a patent system is a device with which appropriability is artificially attached to technological knowledge that is inherently non-appropriable. On the one hand, it is socially desirable to use a technology widely until the marginal benefit from its use is equal to the marginal social cost of the use (say, the cost of making a photo copy) which can be negligibly small in comparison to the marginal cost of invention. On the other hand, such a wide use will deprive the inventor of an opportunity to appropriate monopoly profits from the invention, thereby hurting the incentive for R&D. Ideally, a patent system must be designed so as to achieve the best balance between these conflicting demands. It should encourage inventions by allowing inventors to appropriate monopoly returns for a finite period but, afterwards, the technologies should be made public.[2]

Are patents really effective in creating the appropriability? A questionnaire study by Levin et al. (1987) suggests that other means, such as lead time, learning effects, and secrecy, may be more effective in protecting the competitive advantages from new innovation. Furthermore, the effectiveness of patents for appropriation differs greatly among industries. Most notably, it is high in drugs but relatively low in general machinery, electrical equipment, and transportation equipment. A similar tendency was confirmed for Japanese firms by Goto and Nagata (1996).

These results indicate that the relative values of patents and R&D may differ in an important fashion among industries. We intend to examine this industrial difference empirically. Needless to say, there are other determinants of technological capabilities that are equally important; for instance, production knowhow, worker skills, lead time, learning effects, and the possession of industrial standards. Unfortunately, these are not quantifiable and we confine our comparison to that between patents and R&D.

Section 2 presents the model. It is based on Cockburn and Griliches (1987) but we will propose a new methodology in order to investigate the relative weights of patent stock and R&D stock as measures of technological assets, and to investigate the extent that the capital market relies on the firm's recent R&D expenditures to predict its future profitability. Section 3 discusses the estimation methodology and data, while Section 4 presents the results Section 5 gives the summary and conclusion.

2. The Model

Several authors have estimated the contribution of intangible assets to Tobin's q (Cockburn and Griliches,1987, 1988; Griliches, Hall, and Pakes, 1991; Hall,1993; Hirschey,1985; and Megna and Klock,1993). They used R&D expenditures (or its stock) and/or the number of patents as the proxies for intangible assets, except that Hall and Hirschey also included variables on advertising. We will also confine our study to the estimation of the contributions of R&D and patents, ignoring non-technological intangible assets, such as goodwill, brand, and reputation. In a preliminary study, we included advertising expenditures as an additional explanatory variable. However, the sample size was severely reduced because many firms do not report advertising expenditures and, even when reported, their reliability was questionable. Probably for this reason, the regression failed to show a significant effect of advertising. We therefore decided to concentrate on the estimation of the effects of technological intangible assets.

Let A_t denote the level of tangible assets in year t and K_t, that of intangible assets. Then, using Wildasin's (1984) q theory with many capital goods and using local linear approximation, the market value of the firm, V_t, is written as follows:

$$V_t = a(A_t + \beta K_t) \tag{1}$$

where a is a positive parameter that depends on the adjustment cost in the investment of tangible assets and $a\beta$, that of intangible assets. β may be interpreted as the relative shadow price. If it is smaller (resp. bigger) than unity, the marginal contribution of intangible assets on the market value is weaker (resp. stronger) than that of tangible assets.

Since Tobin's q is defined as the ratio of V_t to A_t, we have

$$q_t \equiv \frac{V_t}{A_t} = a\left(1 + \beta \frac{K_t}{A_t}\right) \tag{2}$$

Taking logarithms and exploiting the fact that $\log(1+x) \approx x$ for small x, we have

$$\log q_t \approx \alpha + \beta \frac{K_t}{A_t} \tag{3}$$

where $\alpha = \log a$.

Technological assets, K_t, is measured by the stock of patents and the stock of R&D expenditures, for the reasons discussed earlier. Let PS_t denote the stock of patents and RS_t denote the stock of R&D expenditures, both in year t, calculated with the perpetual inventory method with appropriate depreciation rates (see Data Appendix for the detail). By approximating K_t by a linear combination of RS_t and PS_t, we rewrite (3) as follows:

$$\log q_t = \alpha + \beta \left(\theta \frac{RS_t}{A_t} + (1-\theta) \frac{PS_t}{A_t} \right) \tag{4}$$

where θ is the weight for R&D stock and $1-\theta$ is the weight for patent stock. These are the weights used by the stock market in order to assess the technological strength of the firm, which should influence the market value. Presumably, if patents are powerful means of appropriating returns on invention, θ will be relatively small while, if patents are hardly effective, it will be close to one. To estimate how it differs across industries is one of the major purposes of this study.

Equation (4) is similar to what Cockburn and Griliches (1987, 1988; hereafter CG) used in their study of 722 US manufacturing firms except that we have explicitly formulated the relative weight between the two technology variables. In addition, CG defined what they called an R&D-

news variable, NR_t, as the current year's net investment in R&D. They found the coefficient of NR_t to be much higher than that of the R&D stock and argued that "the market values 'news' in R&D much more highly than past investments or old patents" (CG, 1988, p. 421). However, the assumption that the 'news' should consist of net R&D investment of only this year is arbitrary and we intend to generalize it.

R&D stock, RS_t, and R&D expenditure, RD_t, are related in the following manner:

$$RS_t = RD_t + (1-\delta)\, RS_{t-1} \tag{5}$$

where δ is the rate of depreciation of R&D. As explained above, CG assumed that

$$NR_t = RD_t - \delta \cdot RS_{t-1} \tag{6}$$

To generalize the concept of R&D news, we expand (5) as follows:

$$\begin{aligned} RS_t &= RD_t - \delta \cdot RS_{t-1} + RS_{t-1} \\ &= RD_t - \delta \cdot RS_{t-1} + RD_{t-1} - \delta \cdot RS_{t-2} + RS_{t-2} \\ &= RD_t - \delta \cdot RS_{t-1} + RD_{t-1} - \delta \cdot RS_{t-2} + \ldots + RD_{t-s+1} - \delta \cdot RS_{t-s} + RS_{t-s} \end{aligned} \tag{7}$$

The first 2s terms in the last expression, that is, all the terms except RS_{t-s}, indicate the sum of net R&D investment in the most recent s years. Let us denote it by $RN(s)_t$ and allow a possibility that the stock market responds differently to this variable than to the rest of the R&D stock.[3] We thus rewrite equation (4) as follows:

$$\log q = \alpha + \beta \left\{ \theta \cdot \frac{RS_{t-s}}{A_t} + \phi \cdot \theta \cdot \frac{RN(s)_t}{A_t} + (1-\theta)\, \frac{PS_t}{A_t} \right\} \tag{8}$$

where ϕ is the extra weight placed by the capital market on the net R&D investment in most recent s years relatively to R&D stock up to s years ago.

There is no *a priori* reason to determine if ϕ should be greater than or less than unity. On the one hand, as CG has argued, if the market takes the recent R&D activity of the firm as a better predictor of the current and future technological capabilities of the firm, ϕ must be larger than unity. On the other hand, a substantial lag may exist between R&D spending and the realization of its outcome because research itself may take several years and, furthermore, it may take another year or two to develop a commercially viable new product or new process out of the invention. Indeed, according to the questionnaire study conducted by the Science and Technology Agency (1985), the average years of lag were 3.3 and 5.9 for electrical equipment and chemicals (including drugs), respectively. Therefore, if the stock market is concerned with the present level of R&D stock taking account of the lag, then it may be more sensitive to RS_{t-s} and ϕ may be smaller than unity.

The following empirical study will show that the estimated ϕ is actually larger than unity, supporting CG's R&D-news hypothesis. However, the appropriate number of years for news, s, is larger than one and differs across industries. In this regard, the CG methodology is flawed.

3. Estimation Methodology and Data

Our sample consists of firms in three R&D-intensive Japanese industries among which the effectiveness of patents are expected to differ: drugs, other chemicals, and electrical equipment. We started with a sample of 40 firms in the electrical equipment industry, 41 firms in chemicals, and 24 firms in drugs for which we could obtain all the necessary data.[4] However, heterogeneity was apparent among these firms in terms of business composition.

For instance, among the chemical firms, some were big integrated firms producing diverse chemical products whereas some were concentrating their activity in the relatively narrow field of, say, soda and related products. While most of the chemical firms were selling intermediate products, some were producing final products, such as toiletries or paints. Among pharmaceutical companies, about a half were the producers of mostly ethical drugs but the rest were split into the producers of over-the-counter drugs, the producers of mainly generic drugs, the producers of medical equipment in addition to drugs, and so forth. Owing to this heterogeneity, the initial results for each of these three industries were not satisfactory, leading us to believe that putting all these firms together is unwise.

We therefore created subgroups of more homogeneous firms. In the chemical industry, four subgroups were created: 3 firms as general chemicals (each producing various chemical products), 11 firms as plastics producers, 4 firms producing soda, vinyl chloride and related products, and 5 producers of paint and/or ink. The rest of the chemical firms were diverse and could not be put into any subgroup. In the electrical equipment industry, again four subgroups were created: 5 makers of heavy electrical equipment (such as generators and motors), 6 makers of home appliances, 7 producers of communications and electronics equipment, and 5 producers of electrical parts. As in the chemical industry, the rest of the electrical equipment firms were unclassifiable.

In the drug industry, 9 firms were more or less homogeneous. Their products are basically ethical drugs and cover a wide range of therapeutic categories. They are all R&D-intensive firms and include such major drug companies as Takeda and Sankyo. The rest of the drug companies were heterogeneous and we decided to confine our analysis to these 9 drug companies.

The sample period is 1981-1991 with the details on the variables and data sources given in the appendix. Since ours are panel estimations, the number of observations is 11 times the number of firms in the industry or the subgroup.

As discussed in the previous section, we need to determine the number of years for R&D news, s. Preliminary estimations indicated that the fit is best when s is 1 for electrical equipment, 3 for chemicals, and 4 for drugs. It is thus suggested that the capital market is taking the net R&D investment of just the most recent year as a news to be used in predicting the future trend of R&D

activity of the firms in the electrical equipment industry, perhaps because of the rapid technological change occurring in the industry. In the chemical and pharmaceutical industries, the capital market is taking the net R&D investment of longer periods (three to four years) as the news. This difference clearly implies that the methodology of Cockburn and Griliches that *a priori* assumed s = 1 for all industries is inappropriate.

The mean values of the four variables are shown in Table 1 by industry and by subgroup. The mean q is above unity in any industry and exceeds two among drug companies. As shown in Equation (1), q can be larger than one if intangible assets are important (i.e., βK_t is positive) or if adjustment costs in investment are significant (i.e., a is larger than unity).[5] To estimate the extent of the contributions of intangible assets is the purpose of next section.

In terms of the R&D expenditures as a proportion to real assets, drug companies are most R&D-intensive. Since the sum of RS and RN is the current R&D stock, Table 1 implies that the R&D stock of drug companies is about 40 per cent of their real capital. This percentage is smaller in chemicals and electrical equipment where it is roughly 10 per cent.

By contrast, the number of patents as a proportion to real assets (in million yen) is smallest in drugs. This fact combined with the large R&D stock (as a ratio to assets) need not imply that drug companies are least efficient in their R&D activity, because the concepts and scopes of patents differ among patent categories, particularly between drug patents and machinery-related patents. Whereas the electrical and electronic companies may acquire more than a thousand patents a year, drug companies have never acquired more than a hundred patents. In 1996, for instance, the top ten companies in the number of patent acquisitions in the US were all electrical and electronics firms led by IBM.[6] The same tendency is confirmed in Table 1 by the larger values of PS/A in the electrical equipment industries, particularly among the producers of communications equipment which include NEC (the fourth in the US top ten) and Fujitsu (the eighth).

4. Estimation Results

The results of fixed-effects panel estimation are shown in Table 1. In drugs, all the parameters are positively significant as expected and the R^2 (adjusted for degrees of freedom) suggests that about a third of the variation in q (in logarithm) is explained by technological intangible assets. In chemicals, by contrast, the coefficient of PS/A is significantly negative, in contradiction to the hypothesis that patents constitute a part of technological assets and increase the firm value. The coefficient turns positive, if not always significant, when the estimation was made by subgroup. Obviously, interfirm heterogeneity is serious in the chemical industry, which prevented the hypothetical contribution of patents from being detected in the industry-wide estimation.

This problem is presumably less serious in the electrical equipment industry because the coefficient of PS/A is positive if not significant. However, again the results differ significantly across subgroups. In home appliances and communications equipment, the coefficients are significantly positive as expected, whereas, in heavy equipment and electrical parts, the coefficients were insignificantly negative. We thus re-estimated with the coefficient of PS/A being forced to equal zero in these subgroups.

The significant contribution of patents in the communications equipment industry is easy to understand in view of their active patenting activity discussed earlier. By contrast, the significant contribution in home appliances may appear surprising because non-patentable production knowhow, designs, and marketing (which are not measurable and thus ignored in our study) may be more important for these firms. This subgroup, however, includes such R&D-oriented firms as Victor Company of Japan (JVC), Sony and Sharp which produce not only conventional home electrical appliances, say, TV sets and (in the case of Sharp) washing machines, but also newer electronic appliances, for instance, Sony's *Play Station* and Sharp's *Zaurus* (a more successful Japanese version of Apple's *Newton*). JVC is the inventor of VHS video-cassette system and holds a number of related patents. The inclusion of these firms, we infer, has resulted in the significant coefficient of patents in home appliances.

The coefficients of RS/A and RN/A are all positively significant in drugs, chemicals, and chemical subgroups, indicating that R&D stock is also taken by investors as an important measure of firm's intangible assets. In addition, the coefficients of RN/A are always larger than those of RS/A (that is, ϕ is larger than unity as we will show presently), supporting the hypothesis that investors value recent R&D expenditures more highly to infer the firm's technological potentials. The same tendency is also found in the electrical industry and its subgroups; however, not all the coefficients are significant.

From these estimated coefficients, we calculated the values of β (the relative shadow price of intangible assets), θ (the weight placed on R&D stock relatively to patent stock), and ϕ (the premium placed on net R&D investment during the recent s years). The result is shown in Table 3. It should be noted that the values of β and θ themselves do not have much meaning because they are sensitive to the units in measuring R&D and patent stock. Although both RS and A are in million yen, PS is a counted number and hence PS/A is not free from units. Still, inter-industry and inter-subgroup comparisons are meaningful.

β is largest in drugs, indicating the heavy dependence of drug company's market value on its technological assets. Generally, chemical subgroups have higher β than electrical subgroups but the inter-subgroup difference is large. Paint and ink subgroup has the largest β while other chemical subgroups have the values similar to home appliances and communications equipment which are one seventh to one tenth of the value in drugs.

θ is smallest in drugs, implying that relatively more weight is placed on patent stock by investors in inferring the technological competencies of drug companies. Why? The first answer must be that, as discussed in Section 1, patents are an effective means of appropriating returns on technological assets in these companies. Therefore, their market values are more sensitive to the level of patent stock than in other industries.

Another reason is that the weight of a single patent is much higher in drugs as discussed in the previous section. Whereas a new drug is usually protected by a single patent, a typical electrical, electronic, or communications equipment contains technologies covered by a number of patents. Thus, the number of patents tends to be smaller in the drug industry but a single patent can be more valuable. Table 1 in fact indicated that, as a proportion to real capital, drug companies own just one-fifth of patent stock in comparison to electrical equipment manufacturers. Suppose that we multiply PS/A of drug companies by five to make the numbers comparable to those in the electrical equipment industry. Then, the coefficient of PS/A will be one-fifth of 735.007 (see Table 2), that is, approximately 147. θ will be then calculated as 0.045, which is larger than the value in communications equipment industry.

It is therefore difficult to conclude whether the smaller θ, that is, the larger weight placed on patent stock among drug companies, indicates the higher appropriability by means of patents or the higher value of a single patent. It may indeed indicate the limitation of measuring technological competencies by the count of patent numbers. In the drug industry in particular, it is well known that a few patents result in blockbuster drugs, such as Glaxo's ulcer drug Zantac, but the majority of them contribute to profitability only little. In other words, the *quality* of patents more than the *number* of patents may well be a better measure of the firm's technological assets. The lack of a quality measure prevents us from testing this hypothesis. It is encouraging, however, that, with the number measure alone, we could still confirm the value-enhancing contribution of patents in high-technology industries, particularly drugs.

This contribution is also confirmed by calculating elasticities with the estimated coefficients using mean values. See Table 4. These elasticities, needless to say, are free from units. The elasticity of log q with respect to PS/A is apparently largest in drugs. It is nearly double the elasticities in paint & ink (in which the coefficient was insignificant), home appliances, and communications equipment. Other elasticities are also largest in drugs, indicating that the contribution of technological assets to q is prominent in this industry.

Let us return to Table 3 and examine ϕ. It is larger than unity in any industry, implying that, as hypothesized, investors place a premium on net R&D investment during the recent s years (in comparison to R&D stock s years earlier). Presumably, it is a better predictor of the firm's future technological competencies. It is larger in the electrical equipment industry, particularly in communications equipment and parts, which seems understandable in view of their rapid technical progress. It makes a good contrast to the smaller values in heavy equipment and home appliances in which the dominant manufacturers are relatively less threatened by upstarts.

5. Summary and Conclusion

A patent system has been devised to attach appropriability to technological knowledge and protect the inventor's interests, hence enhancing incentives for invention. This appropriability is bound to be imperfect because, for one thing, it is technically impossible to attach complete appropriability and, for the other, diffusion of knowledge should be fostered (Ordover, 1991). Furthermore, the extent of appropriability is known to vary significantly across industries. In this paper, we purported to investigate this inter-industry difference in appropriability by empirically applying the multiple q theory to the Japanese drug, chemical, and electrical equipment companies.

A similar study has been made in the US by Cockburn and Griliches (1987) in which they used the index of appropriability obtained by the questionnaire study of Levin et al. (1987). No such index is available in Japan and we confined our analysis to industrial comparison. In addition, we proposed two methodologies. The first was to calculate the technological assets of the firm as a linear combination of R&D stock and patent stock. This enabled us to estimate the relative weights of these two stocks and compare them across industries. The second was to examine if the stock market is biased on the net R&D investment of recent s years (called R&D news) in evaluating the technological capabilities of the firm. Whereas Cockburn and Griliches *a priori* constrained s to be one, we allowed it to vary across industries.

R&D stock, R&D news, and patent stock all had expected positive coefficients against Tobin's q (in logarithm) except for the coefficients of patent stock in a few industries. In addition, the results clearly indicated that the stock market responds to technological assets most strongly and places the largest emphasis on patent stock in the drug industry, coinciding with the common knowledge that it is the most technology-oriented industry and that patents as a means of appropriation are most effective there (Levin et al., 1979; Goto and Nagata, 1996). The larger values (and the smaller number) of drug patents in comparison to patents in other industries may be another reason for the finding. The communications equipment industry was also characterized by the large weight placed on its patent stock. This industry was also characterized by the large influence of R&D news, perhaps because of the rapid technological progress occurring in the last decade in this industry.

Needless to say, patents and R&D are not the only sources of firms' intangible assets. In drugs, the goodwill established among medical doctors is an important asset which most drug companies have created and maintained with the employment of a large number of medical representatives (detailers). In the electrical equipment industry, the production skills and knowhow are also important as well as the brand power and marketing skills. In chemicals, some of the firms are consumer-oriented and the brands may be the most important source of their strength whereas the producers of intermediate chemical products may value the vertical relationship with their material suppliers and buyers. Most of these other intangible assets are not quantifiable and necessarily omitted in our study. In view of this fact, the adjusted R^2 of 0.34 in the drug industry and more than 0.5 in some of the industries is encouraging.

More efforts are certainly needed to produce more reliable measures of a firm's technological competencies, by incorporating other aspects of technology and taking into account the quality differences among patents. The design of a better patent system is an urgent social issue that can be best pursued only with our understanding of the role of patents through these efforts.

Data Appendix

1. Data Source

The primary data sources are *NEEDS Database* (Tokyo: Nihon Keizai Shimbun Sha) for company financial data including R&D expenditures, *Kabuka Souran* (Stock Price Dababook, Tokyo: Toyo Keizai) for share prices, *Bukka Shisu Nenpo* (Price Indexes Annual, Tokyo: Bank of Japan) for wholesale price indexes, *Shigaichi Kakaku Shisu* (City Land Price Indexes, Tokyo: Nihon Fudosan Kenkyusho) for land prices, *Kokumin Keizai Keisan Nenpo* (Annual Report on National Accounts, Tokyo: Economic Planning Agency) for the depreciation rates on physical assets, *Kagaku Gijutsu Kenkyu Chosa Houkoku* (Report on the Survey of Research and Development, Tokyo: Management and Coordination Agency) for R&D deflators, and *Koukoku Tokkyo-suu Nenkan Sakuin* (Annual Indexes on the Number of Patents, Tokyo: Nihon Tokkyo Joho Kiko) for the number of patents issued.

2. Market Value

The market value of the firm was calculated by multiplying the market price of a share of common stock to the number of shares outstanding, and then adding the book value of debt, on the assumption that the discrepancy between the book value of debt and its market value can be ignored.

3. The Current Value (Replacement Value) of Assets

Under the Japanese accounting rule, basically all the assets are evaluated by acquisition costs without subsequent re-evaluation. Hence, we need to estimate the current value (namely, the replacement value) of assets. The estimation method differs among four types of assets -- land, tangible assets (except land), equity, and others.

Land

We started with an assumption that the book value of land equalled the current value in 1955, which must be acceptable because 1955 is 25 years earlier than the start of our estimation period, 1980. We also assumed that the increase in the book value of land was caused by new acquisition of land (in current value). This assumption is safe insofar as the firm is buying and not selling land, which usually was the case. We thus write as follows:

$$LC_t = LC_{t-1} \times (PL_t/PL_{t-1}) + (LB_t - LB_{t-1})$$

where LC_t is the current value of land, LB_t is the book value, and PL_t is the land price, all in year t.

Tangible Assets

These include buildings and structures, machinery, transportation equipment, and instruments and tools. Let KB_t denote the book value of assets net of accumulated depreciation; then, the net investment in book value (NI_t) is:

$$NI_t = KB_t - KB_{t-1}$$

and we calculate the current value of assets (KC_t) as follows:

$$KC_t = KC_{t-1} \times [PK_t/PK_{t-1}] + NI_t$$

where PK_t is the capital-goods price index (the average of construction materials, machinery, and transportation equipment components of the wholesale price index). We thus ignored the discrepancy between the book value of depreciation, which is based on the acquisition cost, and its current value. Since the latter is usually larger, NI_t is likely to overestimate the current-value net investment and, consequently, KC_t is likely to overestimate the current-value assets.

Equity

Equity consists of shares for investment purposes and shares for non-investment purposes (e.g., those of subsidiaries). For the latter, we ignored any discrepancy between the book value and the current value. For those for investment purposes, we assumed that they have earned the market average yield; hence, denoting the shares for investment purposes by EI_t and those for non-investment purposes by EN_t, both in book value, we have the current value of equity, EC_t, as follows:

$$EC_t = (\text{Total dividends received})[EI_t /(EI_t + EN_t)] / (\text{average yield of dividend}) + EN_t$$

Others

For other assets, such as cash and inventories, the book values were assumed to equal the current values.

4. Tobin's q

q was calculated by dividing the market value of the firm by the sum of the current values of the four types of assets.

5. R&D Stock

Denote R&D stock in year t by RS_t and R&D expenditure by RD_t. They are related as follows:

$$RS_t = RD_t + (1-\delta) RS_{t-1}$$

where δ is the rate of depreciation of R&D. By iteration, we get

$$RS_t = RD_t + (1-\delta)RD_{t-1} + (1-\delta)^2 RD_{t-2} + \dots + (1-\delta)^{T-1} RD_{t-T+1} + (1-\delta)^T RS_{t-T}$$

Assuming that RD_t had increased at a constant rate (g) until year t-T+1, we approximate RS_{t-T} as follows:

$$RS_{t-T} = \frac{RD_{t-T+1}}{\delta + g}$$

We took T to be 7 years and approximated g by the average growth rate of RD_t during these 7 years. The rates of obsolescence, calculated by the Science and Technology Agency (1985) based on its questionnaire study to private firms, are 13.9 per cent for electrical equipment and 9.2 per cent for chemicals including pharmaceuticals. As discussed in the text, RS_t was then divided into the two components, $RN(s)_t$ and RS_{t-s}.

6. Patent Stock

The patent stock was computed similarly to the R&D stock, except that we took T to be five years and that the rates of obsolescence, taken from Goto (1993), are now 10.8 per cent for electrical equipment and 13.6 per cent for chemicals including pharmaceuticals. Furthermore, we ignored the initial stock, that is the patent stock in year t-T, because the fewness of patents in some companies (particularly, drug companies) made it implausible to assume any growth rate *a priori*.

Notes

1. Historical analyses of business development along these concepts have been conducted by Chandler (1990) for American, British, and German cases and Odagiri and Goto (1996) for Japanese cases.

2. For theoretical models that treat patents as a strategic means for establishing or maintaining a dominant position in the market, see Gilbert and Newbery (1982), Gallini (1984), Shepard (1987), and Rockett (1990). They suggest that, by licensing patents strategically, the firm can deter entry or discourage rivals' R&D activities, in addition to earning royalty from licensing.

3. Needless to say, $NR_t = RN(1)_t$.

4. The unavailability of R&D data for one or more years caused many firms (e.g., Hitachi) to be excluded. In addition, a few firms with untrustworthy R&D or patent figures were excluded.

5. Another possibility is the imperfectness of competition, and the presence of entry barriers. Lindenberg and Ross (1981), Sallinger (1984), and Smirlock, Gilligan, and Marshall (1984) studied the impact of market share, concentration, and other market structure variables on Tobin's q.

6. *Nihon Keizai Shimbun*, January 14, 1997.

References

Chandler, Alfred. D., Jr. (1990) *Scale and Scope*. Cambridge, Mass.: Harvard University Press.

Cockburn, Iain and Griliches, Zvi (1987) " Industry Effects and Appropriability Measures in the Stock Market's Valuation of R&D and Patents," Working Paper, #2465, National Bureau of Economic Research.

Cockburn, Iain and Griliches, Zvi (1988) " Industry Effects and Appropriability Measures in the Stock Market's Valuation of R&D and Patents," *American Economic Review*, 78(2), 419-423.

Gallini, Nancy T. (1984) " Deterrence by Market Sharing: A Strategic Incentive for Licensing," *American Economic Review*, 74(5), 931-941.

Gilbert, Richard J. and Newbery, David M. G. (1982) " Preemptive Patenting and Persistence of Monopoly," *American Economic Review*, 72(3), 514-526.

Goto, Akira (1993) *Nihon no Gijutsu Kakushin to Sangyo Soshiki* [Innovation and Industrial Organization in Japan]. Tokyo: University of Tokyo Press.

Goto, Akira and Nagata, Akiya (1996) "Survey Data ni Yoru Innovation Process no Kenkyu" [A Study of Innovation Process by Survey Data], paper presented at the International Workshop on Appropriability and Technological Opportunity in a Global Economy, Tokyo, organized by the National Institute of Science and Technology Policy, Science and Technology Agency.

Griliches, Zvi; Hall, Bronwyn H.; and Pakes, Ariel (1991) "R&D, Patents, and Market Value Revisited: Is There a Second (Technological Opportunity) Factor?" *Economics of Innovation and New Technology*, 1(3), 183-201.

Hall, Bronwyn H. (1993) "The Stock Market's Valuation of R&D Investment during the 1980's," *American Economic Review*, 83(2), 259-264.

Hirschey, Mark (1985) " Market Structure and Market Value," *Journal of Business*, 58(1), 89-98.

Levin, Richard C. (1986) " A New Look at the Patent System," *American Economic Review*, 76(2), 199-202.

Levin, Richard C.; Klevorick, Alvin K.; Nelson, Richard R.; and Winter,Sidney G.(1987) "Appropriating the Returns from Industrial Research and Development," *Brooking Papers on Economic Activity*, 3:1987, 783-820.

Lindenberg, Eric B. and Ross, Stephen A. (1981) "Tobin's q Ratio and Industrial Organization," *Journal of Business*, 54(1), 1-32.

Megna, Pamela and Klock, Mark (1993) "The Impact of Intangible Capital on Tobin's q in the Semiconductor Industry," *American Economic Review*, 83(2), 265-269.

Odagiri, Hiroyuki and Goto, Akira (1996) *Technology and Industrial Development in Japan: Building Capabilities by Learning, Innovation, and Public Policy*. Oxford: Clarendon Press.

Ordover, Janusz A. (1991) "A Patent System for Both Diffusion and Exclusion," *Journal of Economic Perspectives*, 5(1), 43-60.

Penrose, Edith T. (1959) *The Theory of the Growth of the Firm*. Oxford: Basil Blackwell.

Rockett, Katharine E.(1990) "Choosing the Competition and Patent Licensing," *RAND Journal of Economics*, 21(1), 161-146.

Sallinger, Michael A. (1984) "Tobin's q, Unionization, and the Concentration-Profits Relationship," *Rand Journal of Economics*, 15(2), 159-170.

Schumpeter, Joseph A. (1942) *Capitalism, Socialism, and Democracy*. New York: Harper and Row.

Science and Technology Agency (1985) *Kagaku Gijutsu Hakusho 1985* [White Paper on Science and Technology, 1985]. Tokyo: The Printing Bureau of the Ministry of Finance.

Shepard, Andrea (1987) "Licensing to Enhance Demand for New Technologies," *RAND Journal of Economics*, 18(3), 360-368.

Smirlock, Michael; Gilligan, Thomas; and Marshall, William (1984) "Tobin's q and the Structure-Performance Relationship," *American Economic Review*, 74(5), 1051-1060.

Teece, David J.; Pisano, Gary; and Shuen, Amy (1992) "Dynamic Capabilities and Strategic Management," Working Paper, University of California at Berkeley.

Wildasin, David (1984) " The q Theory of Investment with Many Capital Goods," *American Economic Review*, 74(1), 203-210.

Table 1. Industry Averages

Industry	q	RS/A	RN/A	PS/A	No. of firms
Drugs	2.1522	.24610	.16235	.00070	9
Chemicals	1.4234	.08831	.02693	.00179	41
General	1.3064	.08974	.03084	.00155	3
Plastics	1.4849	.08652	.02617	.00210	11
Soda & vinyl chloride	1.1910	.10130	.03677	.00147	4
Paint & ink	1.4684	.04280	.01377	.00167	5
Electrical	1.6985	.07799	.01038	.00356	40
Heavy equipment	1.74841	.07022	.00536	.00340	5
Home appliances	1.79005	.08504	.00985	.00306	6
Communications equipment	1.64456	.10665	.01720	.00392	7
Parts	1.69839	.04571	.00594	.00207	5

Table 2. Estimation Results

Industry	RS/A	RN/A	PS/A	Adj. R^2
Drugs	2.2791 (1.8773)*	7.0228 (4.6308)***	735.007 (2.1725)**	.3355
Chemicals	1.8322 (3.1329)***	5.8528 (6.7597)***	-92.5530 (-4.6424)***	.3184
General	2.5549 (2.7272)**	6.5438 (2.3692)**	69.8721 (0.4440)	.6609
Plastics	3.7906 (2.0552)**	6.9829 (3.4023)***	88.9037 (1.8386)*	.2071
Soda & vinyl chloride	2.3721 (3.2190)***	6.1097 (4.5864)***	76.1187 (1.4920)	.5097
Paint & ink	11.6213 (2.9256)***	11.9243 (2.8682)***	166.9431 (1.4163)	.3436
Electrical	0.3558 (0.9380)	2.8747 (2.1962)**	5.3827 (0.5315)	.2430
Heavy equip.	6.2979 (2.3345)**	9.6849 (1.0327)		.1885
Home appliances	2.0836 (0.3834)	2.5053 (1.7510)*	84.5415 (2.4570)**	.2244
Communica-tions equip.	0.3246 (0.7187)	2.2940 (1.7367)*	65.177 (2.6979)***	.4626
Parts	1.4614 (0.6081)	15.2136 (1.7589)*		.1033

Notes:
(a) Panel estimation with firm-wise fixed effects.
(b) Sample size in estimation is 11 times the number of firms as shown in Table 1.
(c) In parentheses are t-values. ***, **, and * indicate significance at, respectively, 1, 5, and 10 per-cent levels two-tailed.
(d) For heavy equipment and parts, equations without the term of PS/A were estimated (see the text).

Table 3. Estimated Parameters

Industry	ϕ	β	θ
Drugs	3.0813	737.2861	.00309
Chemicals			
Integrated	2.5612	72.4270	0.03527
Plastics	1.8421	92.6943	0.04089
Soda & vinyl chloride	2.5756	78.4908	0.03022
Paint & ink	1.0260	178.5644	0.06508
Electrical	8.0795	5.7385	0.06200
Heavy equip.	1.5377	6.2979	1
Home appliances	1.2023	86.6251	0.02405
Communications equip.	7.0671	65.5016	0.00495
Parts	10.4096	1.4614	1

Note: Calculated from the estimated coefficients (shown in Table 2). The figures for chemicals are suppressed because the coefficient of PS/A was negative. In heavy equipment and parts, θ was *a priori* set equal to unity.

Table 4. Estimated Elasticities

Industry	RS/A	RN/A	PS/A
Drugs	.5688	1.1401	.5145
Chemicals	.1618	.1576	-.1656
General	.2292	.2018	.1083
Plastics	.3279	.1827	.1866
Soda & vinyl chloride	.2402	.2246	.1118
Paint & ink	.4973	.1641	.2787
Electrical	.0277	.0298	.0191
Heavy equip.	.4422	.0519	
Home appliances	.1771	.0247	.2586
Communications equip.	.0346	.0394	.2554
Parts	.0668	.0903	

Note: The figures show the elasticities of log q on respective variables, calculated with the estimated coefficients (shown in Table 2) and evaluated at the means.