An analysis of diversification dynamics of R&D activities and external collaboration in major manufacturing industries in Japan

NORIYUKI SHIKATA, HIROSHI IMAHASHI, KIMINORI GEMBA

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Abstract

Numerous studies have been conducted on diversification, but few have analysed diversification dynamics in the manufacturing industry. Open innovation has recently drawn attention, yet few empirical studies have demonstrated the trend in R&D collaboration among business enterprises. This study quantitatively analysed a substantial amount of statistical data regarding the R&D expenses of Japanese manufacturing industries to crosslink the study fields of diversification and R&D collaboration so as to fill the research gap in the preceding studies. The findings of the analysis were as follows: (1) the automobile and accessories manufacturing and pharmaceutical manufacturing industries have focused on their core business and actively collaborated with external parties to acquire fundamental technologies from outside; (2) the other seven major manufacturing industries exhibit high levels of R&D diversification but relatively low rates of external expenditure; (3) the science-based automobile and accessories manufacturing industry and pharmaceutical manufacturing industry have built up a long-term collaborative relationship with partner organisations through academic–industrial collaboration or the effective utilisation of R&D investment to encourage partner companies to acquire new technology from outside. This study successfully visualised the relationship between the 21 years of R&D diversification and R&D collaboration in nine major manufacturing industries in Japan. It thereby contributed to the academic study of diversification by providing a better overall understanding of the R&D diversification of major manufacturing industries in Japan seeking to enter new fields.

Key words

Diversification dynamics, R&D collaboration, open innovation, manufacturing industries

Noriyuki Shikata[1]
e-mail: shikata.noriyuki@iput.ac.jp
International Professional University of Technology in Osaka, Japan

Hiroshi Imahashi
e-mail: h-imahashi@shinonome.ac.jp
Matsuyama Shinonome Junior College, Japan

Kiminori Gemba
e-mail: gemba@hosei.ac.jp
Hosei University, Japan

[1] Corresponding author

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Introduction

Numerous studies have been conducted on diversification, but few have analysed diversification dynamics in the manufacturing industry. Open innovation has recently drawn attention, yet few empirical studies have demonstrated the trend in R&D collaboration among business enterprises. A substantial amount of statistical data regarding the R&D expenses of Japanese manufacturing industries was quantitatively analysed to cross-link the study fields of diversification and R&D collaboration so as to fill the research gap in the preceding studies.

In recent years, many studies have noted that Japanese corporate R&D activities are not continuously profitable (Fukui and Ushijima, 2007; Shikata et al., 2019; Miyazawa, 2019; Imahashi et al., 2020). One of the indices for quantitatively understanding the relationship between R&D as an input and the earnings of a business as an output is R&D investment efficiency (i.e. an index obtained by dividing earnings by R&D expenses). In recent years, Japanese industry has seen a significant decline in R&D investment efficiency (Ministry of Economy, Trade and Industry, 2021). Japan has been one of the leading countries in terms of input (i.e. R&D expenditure) relative to its GDP. Nevertheless, the output (i.e. business profits) has not been commensurate with the contributions made. Therefore, the efficiency of R&D investment has declined annually and remains lower than that of other countries. Japanese companies are now promoting R&D to create new business opportunities to tackle this situation. Some companies are encouraging R&D activities to acquire new technologies through strategic collaboration with outside companies, universities, and public institutions. This study analyses the diversification of R&D activities in nine major manufacturing industries in Japan to identify the extent to which R&D in each industry is moving into new fields. Moreover, we investigate the outsourcing and reception of R&D by research entities, universities, public institutions, and other organisations to explore the status of and trends in their external collaborations with respect to acquiring new technologies. Furthermore, we scrutinise the relationship between the diversification and externalisation of R&D activities in these nine major manufacturing industries.

1. Literature review

In the literature on business diversification, a number of American and European studies have analysed the relationship between diversification and profitability by classifying diversification strategies into different types. The many classification approaches to diversification strategies can be placed into two main categories: diversification in related fields and diversification in unrelated fields. As a representative study of diversification, Rumelt (1974) introduced a classification method to divide the diversification strategy into seven categories: single business (S), vertical business (V), dominant-constrained (DC), dominant-linked (DL), related-constrained (RC), related-linked (RL), and unrelated business (U). He analysed the correlation between diversification and profitability in 246 companies and concluded that companies which diversified only in areas related to their 'core competency and competitiveness' were more profitable. Similarly, other studies have shown that 'companies that diversified in related fields' are more profitable than 'those that diversified in unrelated fields' (Christensen and Montgomery, 1981).

In Japan, Imai et al., (1975) and Yoshihara et al., (1985) conducted detailed investigations based on quantitative empirical methods. Yoshihara et al., (1985) sampled more than 100 representative enterprises in Japan and reported that the correlation between the diversification of Japanese businesses and their performance is nearly equivalent to the correlation obtained from the aforementioned empirical results (Rumelt, 1974). Furthermore, Kodama

(1995) noted that downstream diversification is strongly correlated with sales growth in high-tech industries, indicating that industries with declining export competitiveness diversify in the upstream direction. In addition, some research results have shown, using detailed statistical data from Japanese manufacturing industries, that diversification into unrelated fields reduces profitability (Gemba and Kodama, 2001). Some studies of diversification exclusively analyse specific industries. For instance, the results of an investigation targeting software industries showed that diversification dedicated to the core business in the software industry would yield a long-term profit (Zahavi and Lavie, 2013). As for the medical equipment industry, the richer the company's innovation experiences, the higher the possibility of diversification (Wu, 2013). Another study investigated the diversification of manufacturing industries within the service business and concluded that it would yield a long-term profit, not only through innovative service business models but also through the realisation of product innovation (Visnjic et al., 2014). Several studies analysing the correlation between diversification level and profitability in companies have also noted that diversification would improve a company's profitability to a certain degree, but an excessive level of diversification would degrade its profitability (Hashai, 2015; Santarelli and Tran, 2016; Oladimeji and Udosen, 2019).

However, relatively little research has been conducted on R&D diversification. In the United States, Lerner (1994) showed that the greater the technology domain of the patents held, the higher the value of bio-venture businesses. Using diversification analysis of R&D expenditures, Gemba and Kodama (1999) found downstream technological opportunities for high-tech and scale-dependent industries and upstream opportunities for chemical industry–related industries. Suzuki and Kodama (2005) analysed patents of representative electronics and pharmaceutical companies in Japan, finding that the diversification of core technologies contributes to product diversification and increases revenues. Yamaguchi (2009) concluded, based on the results of an entropy analysis of Japanese companies from FY2000 to FY2004, that the higher the degree of technological diversification, the lower the profitability. Thus, studies on technological diversification are primarily based on analysing the relationship between technological diversification as an input and profitability as an output. In other words, R&D diversification research, including business diversification research, focuses on profitability as the objective variable.

In addition, 'open innovation study' is a research field closely linked to R&D diversification. Chesbrough (2003) proposed a broad concept, arguing as follows:

> If companies are to continue their technological innovations, they need to utilise and develop their internal and external ideas within the labs or at the outside to commercialise these ideas. Open Innovation is a type of endeavour creating new values by organically combining companies' internal and external ideas.

Notable studies in the open innovation field include a report which indicated that the level of innovation would be determined according to the application procedure of the external technologies (Parida et al., 2012) and a study that demonstrated that project success depends on the project management of open innovation (Du et al., 2014). Laursen and Salter (2014) argue that a firm pursuing continuous profitability from innovation must successfully manage both elements of external collaboration, and the strength of the firm's appropriability is represented by patent, design, and brand.

As mentioned above, studies on open innovation have pointed out the significance of R&D collaboration with various external research organisations. This type of study demonstrated that not only large enterprises (LEs) but also small- and medium-sized enterprises (SMEs), universities, and public research institutes actively implement R&D collaborations (Teirlinck and Spithoven, 2013; Belderbos et al., 2015; Cygler and Wyka, 2019). As Chesbrough (2003) has argued, open innovation is quite a broad concept that 'would make an innovation by combining internal and external resources in the company.' At the same time, numerous studies on open innovation address R&D collaboration. In other words, open innovation and R&D collaboration studies are so closely related that, in a sense, the latter can be categorised as a form of the former. For example, Hung and Chou (2013) investigated 176 Taiwanese high-tech manufacturing industries and found that technology acquisition would positively correlate with profitability, whereas technology exploitation would cause a negative correlation with profitability. Several other studies also indicated functional or geographical differences in R&D collaboration between organisations; in other words, the diversity of external organisations with which to collaborate would influence the success of the innovative products resulting from the collaboration (van Beers and Zand, 2013; Maietta, 2015). By focusing on the relationship between corporations in R&D collaboration, another study argued that those corporations engaged in vertical collaboration would be more successful than those engaged in horizontal collaboration (Santamaria and Surroca, 2011). By measuring the effect of academic–industrial collaboration between corporations and universities in R&D collaboration, another study also demonstrated that the academic–industrial collaboration supported by public funds would promote R&D in corporations and favourably influence the business and economic growth of the corporations (Scandura, 2016). As mentioned above, R&D collaboration is academically positioned as one of the methodologies in open innovation.

To summarise the above, two types of diversification exist: business diversification and R&D diversification. These studies focus on the corporation's profitability as the target variable and investigate how to increase the variable effectively. However, studies of 'open innovation' and 'R&D collaboration' are both related to the tactics of acquiring new technologies or knowledge, even though previous studies have treated them as separate, without any overlap. They were in a mutually dependent relationship in terms of corporation or organisation management; smooth coordination is a vital factor in successful management.

One of the richest and most detailed statistical databases by industry in Japan is the 'Survey of Research and Development' by the Statistics Bureau of the Ministry of Internal Affairs and Communications (MIC), which was used in this study for the purposes of analysis. The database is a long-term project in which relevant data have been accumulated and managed strictly by the Statistics Act: specifically, the statistical data following the flow of R&D expenditure invested by corporations or organisations to implement diversification and R&D collaboration. The actual status of the correlation between the management strategy of diversification and acquisition tactics of R&D collaboration was investigated by analysing the flow of R&D expenditure to crosslink the previously separated study fields of diversification and R&D collaboration. The intent was to fill the research gap in the preceding studies.

2. Analysis of the degree of diversification in R&D activities in the nine major manufacturing industries

2.1. Analytical data

Most studies on diversification have been based on an analysis of firm-level data. However, many Japanese companies do not publish detailed sales data for their business sectors. Additionally, constraints on data collection have limited the analysis targets of diversification studies to approximately 100 companies at most, and inadequate data have also made detailed quantitative analysis difficult.

In fact, statistical data on diversification have been available in Japan for many years. The statistical data are based on a large-scale survey of not only large Japanese enterprises but also SMEs, and thus provide detailed and objective information. In addition, these statistics are based on the Statistics Law, which requires companies to provide accurate data; thus, the data are rigorously compiled and sufficiently reliable. Among such government statistics on the diversification of R&D expenditures are those in the 'Survey of Research and Development' by the Statistics Bureau of the MIC. It is based on a survey of R&D investments by product fields for each company since 1970 and then aggregated by industry. For example, even manufacturing companies whose main business is iron and steel invest in R&D not only for their primary iron and steel products but also for chemical, communications, electronics, and other products. Companies are required to report their own R&D expenditures in statistical tables for each product category; the results are published on the website of the MIC Statistics Bureau every year. For the analysis in this study, we used data from the 'Survey of Research and Development' by the MIC Statistics Bureau.

2.2. Measuring the degree of diversification in R&D activities

We selected nine Japanese manufacturing industries ordered by the amount of their internal research funding in FY2019 and conducted a survey and analysis of how the R&D of those companies had diversified over the 21-year period from FY1999 to FY2019. The term 'internal research funding' is defined here as the expenses incurred internally within business corporations, non-profit organisations, and universities for research purposes (internal expenses). Within the category of their own funding and outside funding (from external research organisations) the research funds used internally (within the organisation) are included, but those spent externally (external research organisations) in forms such as sponsored research (including joint research) projects are excluded.

In descending order of the amount of research funds used internally in FY2019, the nine industries were as follows: automobile and accessories (22.1%), pharmaceutical manufacturing (9.4%), information and communications machinery and equipment (8.5%), other electric machinery and equipment manufacturing (8.0%), business-use machinery (7.0%), chemicals (6.6%), electrical components and devices (5.8%), production–use machinery (4.0%), and manufacture of general-purpose machinery (2.2%). Each percentage represents the industry's share of the 13,804.4 billion yen in internal research expenditures for all industries in Japan in FY2019; overall, 2,302 companies were surveyed in the nine industries.

For the purpose of this analysis, we created a matrix of internal research expenditures for these nine industries multiplied by 31 product categories based on industry and product categories in the 'Survey of Research and Development'. The 31 product categories were organised as follows: agricultural, forestry, and fishery products; mining; civil engineering and building materials; food products; textiles; pulp and paper; publishing and printing; chemical fertilisers; inorganic and organic chemical products; chemical fibres; oils, fats, and paints; pharmaceuticals; other chemical products; petroleum and coal; rubber products; ceramics, clay, and stone products; iron and steel; non-ferrous metals; metal products; general machinery and equipment; household electric appliances; miscellaneous electrical machinery and equipment; information and communications machinery and equipment and electrical components; automobiles; aircraft; rolling stock; other transportation machinery; precision industrial products; other industrial products; electricity and gas; software and information processing; and others. On the basis of this composition ratio, the degree of diversification is measured using the entropy value. If the composition ratio of internal research expenditures on product *i* of each industry is P*i*, the entropy value representing the degree of diversification of R&D activities is defined as follows:

$$\Sigma i\ Pi\ \log_2 (1 / Pi)$$

2.3. Results of the analysis of the degree of diversification in R&D activities

Figure 1 shows the trend in the entropy values of diversification (hereinafter referred to as the 'degree of R&D diversification') in the internal research expenditures of the nine industries from FY1999 to FY2019. In the nine industries, the degree of R&D diversification in order from highest to lowest were as follows: chemical industry (2.65), business-use machinery industry (2.23), and manufacture of general-purpose machinery industry (2.18). These industries cover a wide range of product areas: the chemical industry includes 'chemical fertilisers', 'oils, fats, and paints', and 'information and communication equipment'; business-use machinery industry includes 'general tools and machinery', 'information and communication equipment and electronic components', and 'precision industrial products'; and manufacture of general-purpose machinery industry includes 'general goods and machinery', 'automobiles', and 'aircraft'. R&D investments in such diverse product areas indicate a consistently high degree of R&D diversification in these industries over the period FY1999–FY2019.

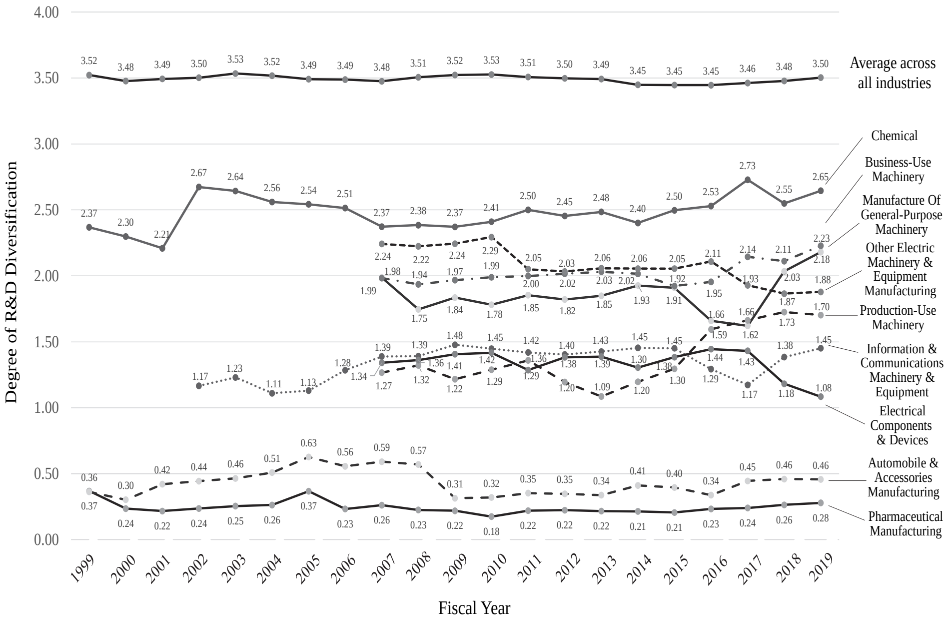
The second-highest level of R&D diversification is to be found in the 'other electric machinery and equipment manufacturing' industry (1.88). The industry's internal research expenditures amounted to 1,109.2 billion yen in FY2019, ranking fourth and accounting for 8.0% among all industries in Japan, indicating that the industry is R&D-oriented. The industry allocates its internal research expenditures mainly to 'other electrical machinery and equipment', the product field of its core business, as well as to 'automobiles' and 'information and communication equipment and electronic components'. Since 2007, when these product categories were established, the industry's expenditure on 'other electrical machinery and equipment' in its core business has been similar to its expenditure on 'automobiles'. After 2011, however, spending on 'automobiles' exceeded that on 'other electrical machinery and equipment' (excluding 2017). In FY2019, in fact, spending on 'other electrical machinery and equipment' was 410.9 billion yen, whereas that on 'automobiles' amounted to 475.7 billion yen (Figure 2).

Additionally, the automotive industry has been promoting a shift to electric vehicles during a 'once-in-a-century' transformational period. In response to this shift, other electric machinery and equipment manufacturing industries are devoting more R&D resources to the automobile product field than to the product field of their main business. Moreover, the industry has reduced its internal research spending on the field of 'information and communication equipment and electronic components' from 201.5 billion yen in 2016 to 126.2 billion yen in 2019.

According to the White Paper Information and Communications 2020, published by the MIC (2020), the exports of ICT-related goods and services for that year were valued at 8.7 trillion yen (nominal value), whereas imports amounted to 12.8 trillion yen, continuing a trend of excess imports since 2011 (note that ICT-related goods include personal computers, cell phones and other communications equipment, integrated circuits and other electronic components, televisions, and radios, whereas ICT-related services include fixed and mobile telecommunications, broadcasting, software services, and newspapers and publishing). Japan's other electric machinery and equipment manufacturing industry has moved rapidly away from spending its internal research resources in the field of 'information and communication equipment and electronic components', partly because of the excess imports of ICT-related goods and services. Subsequently, the production-use machinery industry shows a high degree of R&D diversification (1.70), with its internal research expenditures increasing substantially from 441.5 billion yen in FY2007 to 555.5 billion yen in 2019. Investment in fields other than its core business indicated significant growth for the 'precision industrial products' industry, from 7.5 billion yen in FY2007 to 35.5 billion yen in FY2019. Next, the internal research expenditure of the information and communications machinery and equipment industry (1.45) was 1,168.5 billion yen in FY2019, ranking third among all Japanese companies and accounting for 8.5%, indicating that it is also R&D-focused. However, it is consistently less diversified in R&D activities than other industries, as its internal research expenditures reduced substantially from 2,313.8 billion yen in 2007 to 1,168.5 billion yen in 2019; further, the allocation to its core product area, 'information and communication equipment and electronic components', which accounts for the majority of its products, also declined significantly from 1,700.3 billion yen in 2007 to 865.8 billion yen in 2019. These factors may have contributed to its less diversified R&D activities. Considering this, combined with the aforementioned reduction in investment in 'information and communication equipment and electronic components' by the other electric machinery and equipment manufacturing industry, we can see that the investment in R&D resources in the field of 'information and communication equipment' in Japan has been decreasing in recent years, regardless of the industry. Furthermore, an industry that has traditionally had a low degree of R&D diversification and has recently been even less diversified is the electrical components and devices industry, with a decline from 1.34 in 2007 to 1.08 in 2019. A possible explanation is that while internal research spending fell from 823.1 billion yen in 2007 to 799.4 billion yen in 2019, its investment in the mainstay 'information and communication equipment and electronic components' remained flat, with a minor change from 658.7 billion yen in 2007 to 668.3 billion yen in 2019, and little growth in the field of peripheral products.

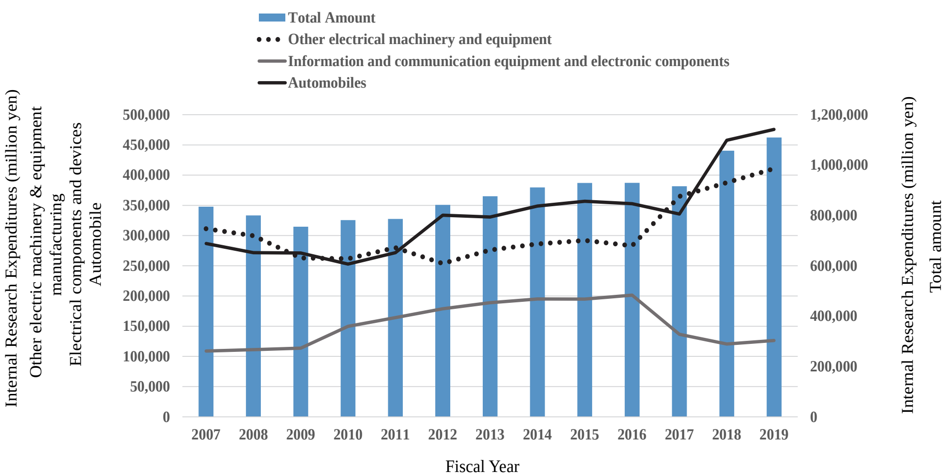
The degree of R&D diversification in Japan's major industrial sectors, automobile and accessories manufacturing and pharmaceutical manufacturing, has also remained low at 0.46 and 0.28 respectively, reflecting the focus of both industries on their core businesses. However, the two industries have achieved remarkable technological innovation. To name but a few examples, the automobile and accessories industry is responding to the 'once-in-a-century' transformation in the automotive industry by developing new technologies associated with motors and batteries to replace engines and gasoline for generating power, as well as electronic components and wires, and automated driving and operation services. Similarly, as biotechnology advances and the drug discovery process changes, the pharmaceutical manufacturing industry is also working to develop new techniques for cell and gene therapies. In other words, both industries are required to conduct targeted and innovative R&D activities to cope with the current business and technological transformation. It should also be noted that further analysis of the diversification and specific strategies for R&D activities in each industry is required.

Figure 1. Diversification of R&D Activities in 9 Major Manufacturing Industries, 1999–2019



Source: own elaboration based on data from the Statistics Bureau of the Ministry of Internal Affairs and Communications of Japan (1999-2019)

Figure 2. R&D Expenditures in Other Electric Machinery and Equipment Manufacturing



Source: own elaboration based on data from the Statistics Bureau of the Ministry of Internal Affairs and Communications of Japan (1999-2019)

3. Externalisation of R&D activities

3.1. Analysis procedures

In this section, we analyse the status of externalisation and acceptance of R&D expenditures for each R&D organisation in Japan with the aim of clarifying actual R&D activities. The analysis refers to the aforementioned report, 'Research Entities, Internal Research Funds, Research Funds Received and Research Funds Paid Externally by Organisation' in the 'Survey on Science and Technology Research' by the MIC Statistics Bureau. This survey report analyses the expenditures for internal, incoming, and external research of corporations, non-profit organisations, and public institutions such as state-run, public, and special corporations, and universities. The most recent version of the survey, FY2019, was used to analyse the data. The organisations surveyed numbered 18,554. The actual R&D expenditures by each organisation are defined as follows:

R&D Expenditure = Internal Research Expenditures + Research Funds Paid Externally

'Research funds received' refers to the amount of money received as research expenses from external sources (from outside research organisations), whereas 'research funds paid externally' refers to the amount of money paid out as research expenses to external parties (from outside research organisations).

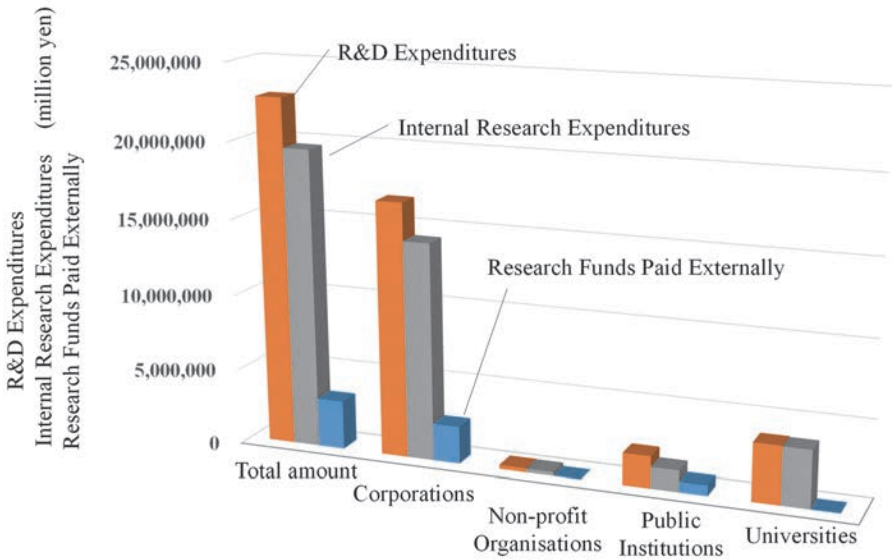
3.2. Results of the analysis

Japan's total R&D expenditures amounted to 22,772 billion yen in FY2019. With respect to the breakdown, 16,660 billion yen (73% of total expenditure) were spent by corporations, followed by 3,766 billion yen (17%) by universities, 2,085.9 billion yen (9.2%) by public institutions, and 260.6 billion yen (1.1%) by non-profit organisations (Figure 3).

Regarding research funds paid externally, corporations ranked first with 2,448.0 billion yen (77% of total expenditure), followed by public institutions with 683.4 billion yen (21%), universities with 46.0 billion yen (1.4%), and non-profit organisations with 19.6 billion yen (0.6%) (FY2019). The growth rate of the research funds paid externally increased by 179%, from 1,784.4 billion yen in 2001 to 3,197.0 billion yen in 2019. In addition, large increases were recorded for universities and public institutions; however, the amounts involved in each case were small. Universities recorded a 1,568% increase (from 2.93 billion yen to 46 billion yen), followed by public institutions with a 363% increase (from 188.4 billion yen to 683.4 billion yen), and corporations, which had the largest external research expenditures, with a 169% increase (from 1,444.4 to 2,448.0 billion yen) (Figure 4).

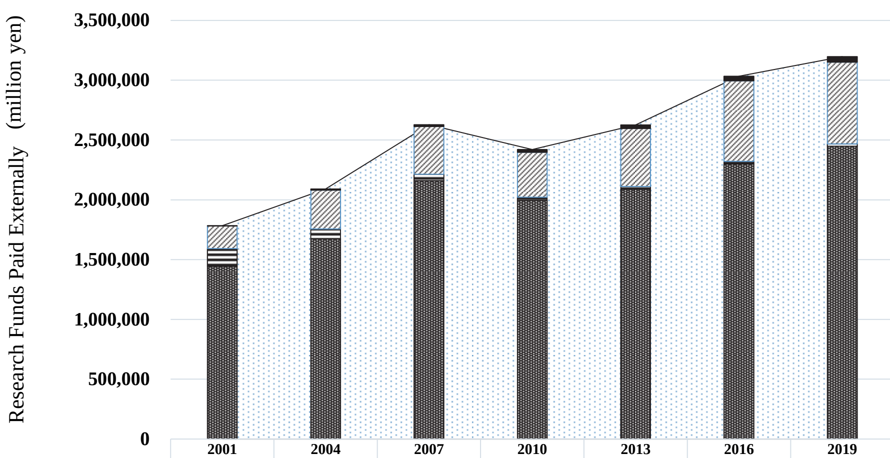
Public institutions received the largest amount of research funds with 1,687.0 billion yen (43% of total expenditure), followed by corporations with 1,270.4 billion yen (33%), universities with 747.0 billion yen (19%), and non-profit organisations with 191.5 billion yen (4.9%) (FY2019). As for the increasing rate of the research funds received by the total amount, FY2019 shows a 123% increase compared to FY2001, from 3,155 to 3,896 billion yen. Universities recorded a 179% increase (from 418.3 to 747.0 billion yen), followed by public institutions with a 152% increase (from 1,108.4 to 1,687.0 billion yen), and in third place, corporations with a 110% increase (from 1,158.5 to 1,270.4 billion yen) (Figure 5).

Figure 3. Breakdown of Research Entities and their R&D Expenses, 2019



Source: own elaboration based on data from the Statistics Bureau of the Ministry of Internal Affairs and Communications of Japan (2019)

Figure 4. Breakdown of Research Entities and the Amount of Research Funds Paid Externally

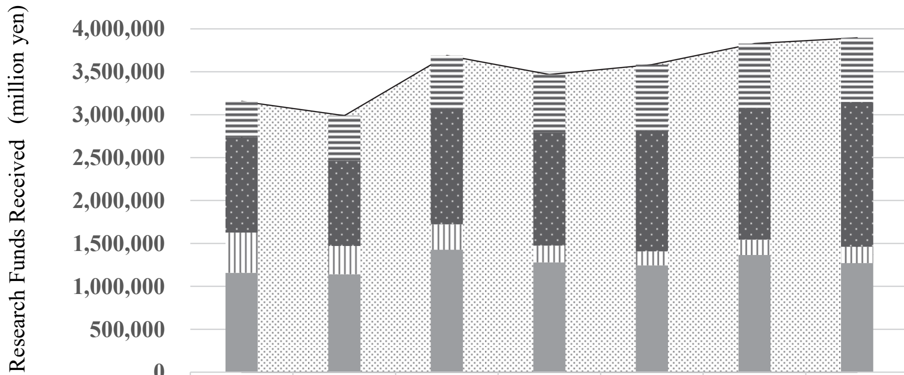


	2001	2004	2007	2010	2013	2016	2019
Total Amount	1,784,395	2,089,938	2,627,904	2,420,681	2,626,908	3,033,093	3,196,966
Universities	2,931	8,490	15,198	23,726	30,834	37,978	45,961
Public Institutions	188,443	324,131	399,461	375,458	484,931	674,683	683,426
Non-Profit Organisations	148,608	82,691	53,634	24,261	22,437	21,175	19,610
Corporations	1,444,414	1,674,626	2,159,611	1,997,237	2,088,706	2,299,257	2,447,969

Fiscal Year

Source: own elaboration based on data from the Statistics Bureau of the Ministry of Internal Affairs and Communications of Japan (2001-2019)

Figure 5. Breakdown of Research Entities and the Amount of Research Funds Received



	2001	2004	2007	2010	2013	2016	2019
Total amount	3,154,939	2,989,493	3,690,699	3,468,573	3,584,540	3,829,630	3,895,961
Universities	418,313	523,771	619,650	672,349	769,108	749,954	746,958
Public Institutions	1,108,436	995,217	1,348,347	1,320,625	1,408,384	1,535,610	1,687,011
Non-Profit Organisations	469,714	328,005	294,622	194,514	160,816	178,867	191,543
Corporations	1,158,477	1,142,501	1,428,080	1,281,085	1,246,232	1,365,200	1,270,449

Fiscal Year

Source: own elaboration based on data from the Statistics Bureau of the Ministry of Internal Affairs and Communications of Japan (2001-2019)

4. Relationship between diversification of R&D activities and external collaboration

4.1. Analysis procedures

Next, we analysed the relationship between R&D diversification and external collaboration. To identify external collaboration tactics developed by companies to promote R&D diversification, we used the external expenditure rate for the R&D index, which is calculated as follows:

External Expenditure Rate (%)
= (Research Funds Paid Externally / R&D Expenditures) × 100.

** Note that R&D Expenditures = Internal Research Expenses*
+ Research Funds Paid Externally

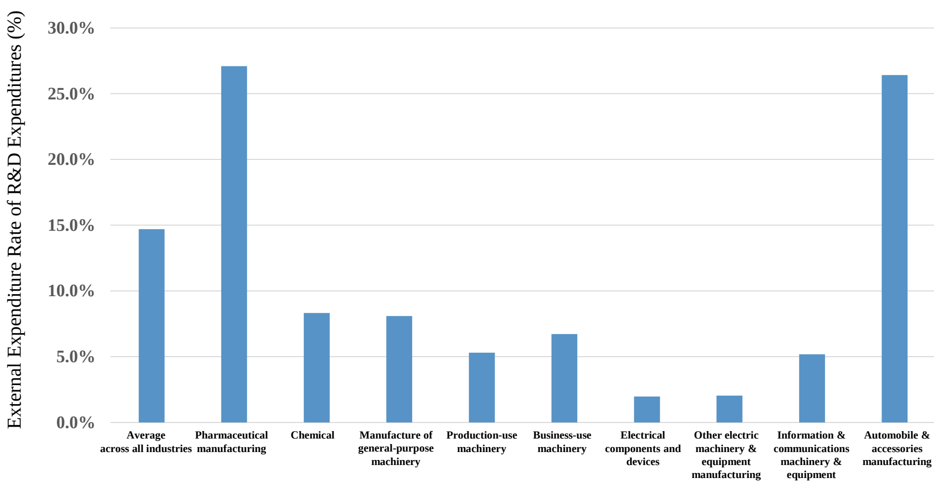
We conducted a single-correlation analysis of the degree of R&D diversification and the rate of external expenditures on R&D activities for the nine major manufacturing industries discussed in the analysis in Section 3 to investigate the relationship between the degree of R&D diversification and external collaboration.

4.2. Results of the analysis

The pharmaceutical manufacturing industry had the highest external expenditure rate (27%) (Figure 6), followed by automobile and accessories manufacturing (26%), chemical industry (8.3%), manufacture of general-purpose machinery industry (8.1%), business-use machinery industry (6.7%), production-use machinery industry (5.3%), information and communications machinery and equipment industry (5.2%), other electric machinery and equipment manufacturing (2.04%), and electrical components and devices (1.96%). Since the average rate across all industries was 15%, it is clear that the external expenditure rates of the automobile and accessories manufacturing and pharmaceutical manufacturing industries were significantly higher than those of other industries, whereas those of the other seven major manufacturing industries were significantly lower than the average.

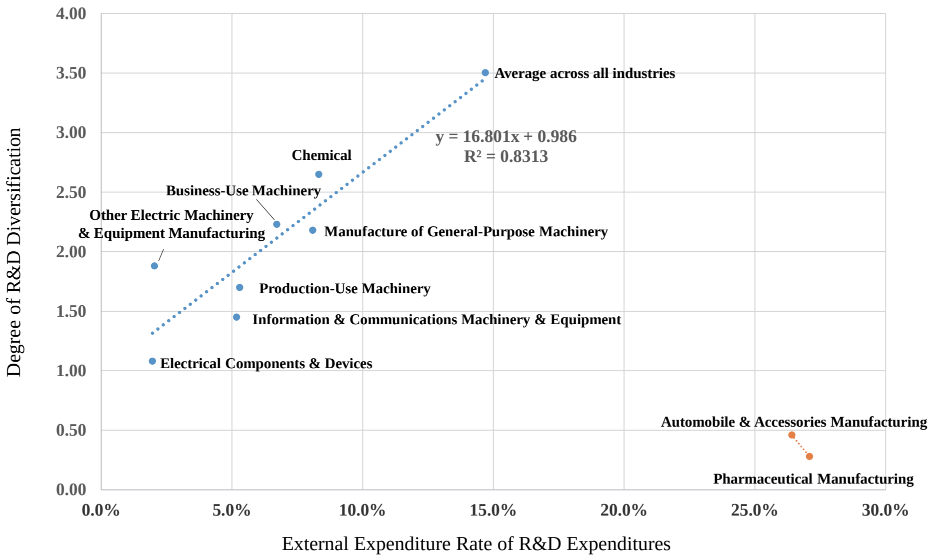
The degree of R&D diversification and external expenditure rates for the nine major manufacturing industries is shown in Figure 7, which is a graphical representation of the single-correlation analysis. On the one hand, for industries with an external expenditure rate of 15% or less (seven major manufacturing industries), we found a positive correlation between the external expenditure rate (%) and the degree of R&D diversification ($y = 16.801x + 0.986$, $R^2 = 0.8313$). On the other hand, for industries with an external expenditure rate of more than 15% (automobile and accessories manufacturing and pharmaceutical manufacturing industries), we found the data to be discrete from the regression line, indicating that the degree of R&D diversification is very low in industries with very high external expenditure rates.

Figure 6. External Expenditure Rate for 9 Major Manufacturing Industries, 2019



Source: own elaboration based on data from the Statistics Bureau of the Ministry of Internal Affairs and Communications of Japan (2019)

Figure 7. Relationship between External Expenditure Rate of R&D Expenditures and Degree of R&D Diversification in 9 Major Industries in Japan, 2019



Source: own elaboration based on data from the Statistics Bureau of the Ministry of Internal Affairs and Communications of Japan (2019)

5. Discussion

5.1. Contributions of R&D diversification and external collaboration to the research fields

This study successfully visualised 21 years of R&D diversification in nine major manufacturing industries in Japan (Figure 1). It makes an academic contribution to the study of diversification by providing an overview so as to enhance an understanding of the R&D diversification of major manufacturing industries in Japan that are entering new fields. The relationship between R&D diversification and external collaboration was also visualised (Figure 7).

Studies on R&D diversification have primarily focused on analysing the correlations between R&D diversification and profitability (Lerner, 1994; Gemba and Kodama, 1999; Suzuki and Kodama, 2005; Yamaguchi, 2009). In other words, the study of R&D diversification is mostly viewed as a research field in management strategy research. However, the study of external collaboration, which is a technology acquisition tactic to realise R&D diversification, consists of studies on project management methods (Du et al., 2014), collaborative relationships with partner organisations (Belderbos et al., 2015; Santamaria and Surroca, 2011), types of technologies acquired through external collaboration (Hung and Chou, 2013), and other relevant topics. Thus, external collaboration is considered a different field from the management strategy field of R&D diversification. In this study, these two fields were successfully crosslinked, and their relationships were visualised, achieving a new academic contribution. As mentioned previously, the relationship between R&D diversification and external collaboration was successfully visualised in terms of nine major manufacturing industries in Japan.

Furthermore, a certain implication arises from merging the findings obtained in this study (Figure 7) with the findings indicated in previous studies. As mentioned previously, this study revealed that the automobile and accessories manufacturing and pharmaceutical manufacturing industries have focused on their core business and actively collaborated with external organisations. Sakakibara et al., (2011) conducted a cross-industry comparison of the 'science-based' factors in Japan's major manufacturing industries in 2007 to determine that the 'automobiles, aircraft, and industrial transportation vehicle' and 'chemicals (including pharmaceutical products)' industries were characterised by a high level of science-based factors, whereas the 'general tools and machinery' and 'electrical appliances and information and communication equipment' industries were marked by a lower level of science-based factors. 'Science-based' factors are considered significant in this study in terms of scientific findings or activities in academic societies, and scientific discoveries are of greater importance in the 'automobile, aircraft, and industrial transportation vehicle' and 'chemicals (including pharmaceutical products)' industries than in other industries. In short, the automobile and accessories manufacturing and pharmaceutical manufacturing industries investigated in this study are science-based industries, creating innovations by building long-term collaborative relationships with external parties, as shown in the following sections.

5.2. Long-term relationship-building by the 'automobile and accessories manufacturing industry' in R&D collaboration

Sakakibara et al., (2011) investigated the joint development of on-vehicle nickel-hydrogen batteries by Toyota Motor Corporation and Matsushita Electric Industrial Co., Ltd. (currently Panasonic Corporation) as an example of the use of scientific findings. Toyota Motor Corporation launched the world's first hybrid vehicle, the first-generation Prius, in December 1997. Its rechargeable batteries were developed almost independently by Matsushita Electric, a specialised nickel-hydrogen battery manufacturer. As the development of these batteries progressed later with minor changes in 2000, followed by the second-generation Prius in 2003, both corporations have deepened their relationship through external collaboration. Later, they jointly launched the new corporation 'Prime Planet Energy & Solutions, Inc.' in January 2019 to realise a stable supply of on-vehicle batteries using Panasonic's lithium-ion battery technology (Toyota Motor Corporation website, accessed on 4 September 2021). As mentioned above, these two corporations have engaged in external collaboration to realise R&D diversification and deepen their relationship with a capital tie-up, building a stable relationship for more than 20 years.

5.3. Externalisation of R&D activities in the pharmaceutical manufacturing industry

In their FY2016 report 'Increasing externalisation of R&D in major Japanese industries', Yaguchi and Tomizawa (2017) compared the 'pharmaceutical manufacturing industry' with 10 other major industries. According to the report, of the partner companies with which the pharmaceutical manufacturing industry entered into joint research agreements, 68.4% were SMEs, and 71.1% were LEs, indicating no significant difference in the size of firms as partners in joint research. Furthermore, they noted that the average rate of investment for the pharmaceutical manufacturing industry is 23.7%, that is, 4.7 times the average of other industries (5.0%). In their view, the sector has seen quite active investment in SMEs, which is considered to be rare in Japan, demonstrating the importance the sector attaches to SMEs. The pharmaceutical manufacturing industry invests significant amounts of money in its collaborating companies; that is, it invests considerable sums externally in R&D to introduce novel technologies. It is a unique characteristic never seen in other industries, showing a high rate of collaboration with SMEs, demonstrating that the partnership with SMEs is far more significant for the pharmaceutical manufacturing industry than for other industries.

Another study by Okuyama (2019) discussed the contribution of 'star scientists' whose achievements in the basic research of pharmaceutical products were outstanding. Academic researchers' scientific knowledge and technologies play a vital role in drug development, and Japanese pharmaceutical corporations have actively engaged in academic–industrial collaboration. In addition to academic society meetings or research publications, he argued that 'open application-type' and 'site-designated-type' collaborations have recently been characterised by steady increases in academic–industrial collaboration opportunities. In 'open application-type' collaborations, the pharmaceutical corporations publish wish lists of their research needs to invite academic researchers to apply joint research plans that accord with their research needs. Corporations such as Shionogi & Company, Ltd., and Daiichi Sankyo Company, Ltd., pioneered this type of programme. Currently, many pharmaceutical corporations in Japan implement similar programmes. In cases of 'site-designated-type' collaboration, industries and academic institutions with the same expertise and technological needs would nominate the partner organisation to collaborate comprehensively in joint research programmes. Okuyama discussed this type of collaboration using examples of joint research projects between Kyoto University and Astellas Pharma Inc., Osaka University and Chugai Pharmaceutical Co., Ltd., or Otsuka Pharmaceutical Co., Ltd., and between the Centre for iPS Cell Research and Application, Kyoto University, and Takeda Pharmaceutical Company Ltd. These examples demonstrate that Japan's pharmaceutical manufacturing industries have actively promoted academic–industrial collaboration and built a continuous partnership with universities to acquire new external technologies.

5.4. Merging with findings of preceding studies

Belderbos et al. (2015) conducted a long-term analysis of the operation of external collaboration in innovative firms in Spain from 2004 to 2011. Partner organisations included suppliers, clients, business rivals, research institutes, and universities. The results showed that continuous external collaboration significantly contributes to innovation performance. Scandura (2016) analysed a substantial amount of data regarding corporations in the United Kingdom to investigate the R&D efforts of these UK corporations engaged in academic–industrial collaboration using public funds. The effects of academic–industrial collaboration were measured to demonstrate that collaboration using public funds would promote R&D activities in corporations and favourably influence the business and economic growth of corporations.

As mentioned previously, the science-based automobile and accessories manufacturing industries exemplified by the case of Toyota Motor Corporation made effective use of a continuous partnership with external collaborators to acquire new technologies from the outside. The pharmaceutical manufacturing industry also made the best of the continuous external and academic–industrial collaboration in partnerships with SMEs (Yaguchi and Tomizawa, 2017) or joint projects with universities (Okuyama, 2019). These results are consistent with the findings of previous studies indicating the significance of long-term external collaboration and academic–industrial collaboration.

Conclusions

The diversification of R&D activities and external collaborations represent crucial challenges to the formulation and implementation of innovation strategies of companies engaged in R&D activities. However, surprisingly few empirical studies have investigated the diversification of R&D activities and external linkages. Therefore, this study attempts to empirically analyse the diversification of R&D activities and external collaboration in nine major manufacturing industries in Japan. The main findings of this study are as follows:

1. Both the automobile and accessories manufacturing and pharmaceutical manufacturing industries are more focused on their core business than the other seven industries. Additionally, the two industries actively engage in external collaboration to acquire fundamental technologies for their core business from outside, which is clearly indicated by their very high rates of external expenditures on R&D.
2. Compared to the automobile and accessories manufacturing and pharmaceutical manufacturing industries, the other seven major manufacturing industries exhibit a high degree of R&D diversification but a low level of external collaboration. In other words, while promoting R&D for a wide variety of products, the seven industries clearly do not reach the levels of the automobile and accessories manufacturing and pharmaceutical manufacturing industries in terms of the ratio of external expenditures on R&D.
3. The empirical findings of comparisons among the other seven major industries show that the higher the R&D diversification level, the higher the external expenditure ratio and the more actively companies engage in external collaboration. Furthermore, both the external R&D expenditure rate and degree of R&D diversification are positively correlated across the seven major industries: $y = 16.801x + 0.986$, $R^2 = 0.8313$.
4. The study revealed that the science-type industries of the automobile and accessories manufacturing industry and pharmaceutical manufacturing industry build up a long-term collaborative relationship with partner organisations through academic–industrial collaboration or effective utilisation of R&D investment to encourage the partner companies to acquire new technology from outside.

On the basis of 'diversification' studies, they focus on the corporation's profitability as the target variable and investigate how to increase the variable effectively. In contrast, studies on both 'open innovation' and 'R&D collaboration' are concerned with the tactics of acquiring new technologies or knowledge. However, previous studies have studied them separately without overlap. Nevertheless, they were in a mutually dependent relationship in terms of corporation or organisation management; smooth coordination is a vital factor for successful management.

In this study, we find that industries with a low degree of diversification actively engage in external collaboration to acquire fundamental technologies for their core business from outside. Specifically, these industries build up a long-term collaborative relationship with partner organisations through academic–industrial collaboration or the effective utilisation of R&D investment to encourage partner companies to acquire new technology from outside.

Furthermore, in the other seven major manufacturing industries, continuous external collaborations with SMEs, universities, and public research institutes are also considered significant. However, a detailed analysis to investigate this matter was not included in the scope of this study. Therefore, further investigation of the relevant topic is mandatory. Moreover, this is industry-oriented research; further analysis by corporation-oriented research must be conducted in the future.

This study quantitatively analyses external collaboration in the R&D activities of Japan's nine major manufacturing industries and finds it to be steadily increasing. However, the direction of specific strategies for external collaboration in the future has not been adequately analysed. As the importance of external collaboration is expected to increase in major industries and SMEs, future studies should build on our findings and address the shortcomings of the study.

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Noriyuki Shikata, PhD, is a professor in the Department of Information Technology at the International Professional University of Technology in Osaka. He received his PhD from Osaka University in 2012. He has successfully started a new business to build social infrastructure for the elderly at Panasonic. In the academic world, he researches technology management and innovation management in order to create a prosperous society. ORCID no.: 0000-0003-2695-7460.

Hiroshi Imahashi, PhD, is an associate professor in the Department of Business Studies, Matsuyama Shinonome Junior College, Ehime, Japan. In 2016, he received a master's degree, as well as a PhD from Osaka University in 2019. His main fields of research are the management of technology, food relation systems, and patent analysis. He holds the qualifications of librarian and museum curator. ORCID no.: 0000-0002-1561-8618.

Kiminori Gemba, PhD, is a professor at the Business School of Innovation Management at Hosei University. His research interests are innovation theories and strategic management. In 1992, he received a master's degree in engineering from the University of Tokyo. Subsequently, he joined the Sanwa Research Institute. He received his PhD from the University of Tokyo in 1999. He then became a research associate and an associate professor at the University of Tokyo and a professor at Ritsumeikan University. ORCID no.: 0000-0002-0309-0764.