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Does R&D for Environmental Improvements Increase Firm Value? Evidence from Japanese manufacturing firm level data

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Abstract

Environment-related investments represent challenges for private sector firms due to uncertainty about their future impact on corporate value and capital formation. Previous empirical research has overlooked such incentive structures. Following the approach of Brynjolfsson, Rock and Syverson (2021), we estimated a firm value function with multiple assets including environment-related R&D as explanatory variables, based on the concept that associated costs of capital accumulation can contribute to future productivity improvements. Our estimation for manufacturing firms finds that environmental R&D contributes to firm value positively and significantly. These effects are particularly evident in large firms and those engaging in technology trade. This suggests that such investments facilitate technological accumulation to meet the demands of international consumers and regulatory frameworks.

However, recent shifts in global policy such as the U.S. withdrawal from the Paris Agreement may weaken incentives for Japanese firms with close ties to U.S. markets. If Japan wants to continue to pursue policy that is aligned with the Paris Agreement, stronger government support for private sector environmental initiatives will be necessary.

Keywords: Environmental R&D, Firm value, Intangible correlates, Technology trade
JEL classification numbers: O35, Q51, Q55

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1. Introduction

There was great enthusiasm for environmental investments in the 2010s, but this seems to have abated in the 2020s. There are two main reasons behind this change. One is political. US President Trump, who took office in 2025, has reversed many environmental policies that were advanced by the government led by former US President Biden. The major US banks have withdrawn from the Net Zero Banking Alliance and the major banks in Japan followed suit.

The other reason is that the amount of environmental investment has been overstated due to the ambiguity of the definition of the term--this is known as “ESG washing”—and this has led to a widespread distrust of claims of such investment.

This volatility in environmental investment is caused by a lack of consensus on what economic effects these investments have on firm performance. Friedman (1970) argued that environmental investment is not a task for private firms, which should concentrate on maximizing dividends. He maintained that supporting environmental investment that increases social welfare is the role of the government.

The argument that environmental activities increase firm value emphasizes the notion that firms that accumulate management resources through these activities have competitive advantages over other firms. Many studies that support this theory estimate the firm value function developed by Griliches (1981), and show positive relationships between environmental activities and firm value.

Griliches (1981), in examining the effects of R&D on firm value, showed the formulation whereby not only tangible but also intangible assets contribute to firm value. Many studies on environmental activities and firm value, such as Cavaco and Crifo (2014) and Endo (2019), apply his formulation to environmental assets accumulated by environmental activities. However, the direct application of Griliches (1981) to environmental issues should be considered carefully, because there exists no clear theoretical foundation that confirms that environmental activities positively affect firm value, like there does for R&D.R&D activities generate profits through new and innovative goods and services and new production processes, environmental activities are more likely to increase production costs in private firms, even if they benefit society as a whole. In addition, because many studies use subjective indices to measure environmental activities, they do not directly reflect environmental assets assumed by Griliches (1981).

Although Miyagawa, Edamura and Uchiyama (2017) examined the relationship between firm value and environmental activities using R&D investment in environmental areas, their empirical approach followed Griliches (1981). In this paper, we propose an alternative empirical approach to the relationship, following Brynjolfsson, Rock and Syverson (2021). Their study starts from the standard neoclassical theory of the investment function. In this theory, the amount of investment is determined by the condition that the marginal efficiency of investment equals the marginal cost of investment. Wildasin (1984) extended this investment theory to multiple assets and showed that the firm value is expressed as a weighted sum of each asset value, where the weight is the marginal adjustment cost of investment for each asset. We estimate this firm value function. Although this function is similar to that in Griliches (1981), Brynjolfsson, Rock and Syverson (2021) argued that the estimated coefficients imply that high adjustment costs contribute to high firm value if these costs are accumulated as intangibles, such as skilled labor and organizational capital. When the estimated coefficient of environmental assets is large and positive, this suggests that the management resources accumulated by environmental activities increase the firm value in the neoclassical framework. In addition, in their framework and in cases of large adjustment costs with environmental investment, firms suffer from a low TFP growth rate in the short run. This implication is also consistent with the fact that many firms are reluctant to conduct bold environmental activities. As a result of fixed effects estimations, we find that the estimated coefficients of R&D on environmental activities are positive and significant.

In addition to the estimation based on the microfoundation of environmental activities, this paper makes another contribution. Unless other firms also conduct environmental activities and the governments enact environmental regulations, firms have little incentive to conduct environmental activities. In particular, to prevent further climate change, companies around the world must also participate in these activities. Hence, we examine how the environmental R&D of firms depends on international activities of firms.

There is a lot of literatures on international technology diffusions. In the macroeconomic perspective, Coe and Helpman (1995) showed that international technology diffusions are induced by trade. Keller (2001) surveyed international technology transfer through not only trade but also foreign direct investment. However, these literatures have not explained why international technological trade relates to the increase in firm value. de Rassenfosse, Parangkaraya and Webster (2016) showed the unique technology represented by patents makes technological trade easier. Escribano, Fosfuri and Tribó (2009) argued that absorptive capacity for new technology obtained through own R&D activities makes external technology to easy to accept and contributes to better firm performance.

Based on these studies, we divide our sample into those with and without technological trade and examine whether environmental R&D stimulated by technological trade affects firm value. As a result, we find that the estimated coefficients of R&D on environmental activities in firms without technological trade are higher than in firms with it. These results imply that the contribution of environmental investment to firm value in firms without technological trade is larger in the long run than that in firms with it, although firms without it pay more associated costs of investment in the short runt.

Our paper consists of five sections. We review the related literature in the next section. In the third section, we explain the data used for our empirical studies. In the fourth section, we show the estimating functions and estimation results. In the final section, we summarize our conclusions and discuss the remaining research issues.

2. Literature Review

As people have been paying attention to climate change since the 1990s, many studies in the area of management science have justified environmental activities for private firms in spite of Friedman's (1970) argument. The theoretical foundation of these studies is based on Hart (1995) and Porter and van der Linde (1995).

Hart (1994) proposed a "Natural Resource-based View" to support environmental activities of private firms. The resource-based view developed by Penrose (1959) and Chandler (1962) argues that the firm's competitive advantage stems from their organizational capabilities in response to changing external circumstances. Hart argued that environmental activities are indispensable for firms to maintain a sustainable competitive advantage. Porter and van der Linde (1995) also supported the view by Hart (1995). They argued that environmental regulations promote environmentally-friendly innovations and firms that are aggressive in environmental activities would gain good reputations from customers.

As for empirical studies on environmental innovations of private firms, Griliches's (1981) study is influential. However, Griliches's (1981) empirical framework cannot be applied to environmental innovations directly, because he showed that profit-making knowledge assets accumulated by R&D activities positively contribute to the market value of a firm.

Using Griliches's (1981) framework and dividing R&D activities into R&D for environmental improvements and other R&D activities, Edamura, Miyagawa and Uchiyama (2017) showed that R&D for environmental improvements positively contributed to market value. In the same framework as Edamura, Miyagawa and Uchiyama (2017), Endo (2019) found that firms' environmental activities, measured by the total scores of environmental management by Nihon Keizai Shimbunsha, have a positive and significant effect on Tobin's Q. The study by Colombelli, Ghisetti and Quatraro (2020) focuses on European firms, and their results are similar to those by Edamura, Miyagawa and Uchiyama (2017) and Endo (2019). However, they constructed a stock of patents related to environmental improvements using the OECD REGPAT dataset and used it as an independent variable in the framework of Griliches (1981). They found positive and significant effects of environment-related patents on market value in many cases. The study by Tian, Dong, Vagnani and Liu (2023) is similar to that of Colombelli, Ghisetti and

Quatraro (2020). Using patent data of Chinese polluting firms, they showed that the increase in environment-related patents positively affected Tobin's Q.

Some empirical studies investigate the relationship between innovative activities in environmental improvements and market value without the Griliches (1981) framework. Flammer (2013) conducted an event study. She gathered corporate news related to environmental activities in the US and investigated the effects of the news on market value. They found that eco-harmful behavior of firms reduces their market value, while eco-friendly behavior has a lesser effect on them. Xie, Hoang and Zhu (2022) divide the total effects of environmental innovation on financial performance, such as profits and return on equity, into short-term and long-term effects. They showed that environmental process innovations, obtained from their unique survey, have positive impacts on financial performance in the long run, while their effects on financial performance are negative in the short run.

In Japan, there are many articles that study the relationship between financial performance and qualitative indices that show environmental activities. Nakao et al. (2007) examined the relationship between Tobin's Q or ROA and the Nikkei Environmental Management Score. They found a positive relationship between financial performance and the indices of environmental management. Hibiki and Managi (2010) examined whether the financial markets evaluate the risks associated with toxic chemical releases and transfers. Iwata and Okada (2011) studied the relationship between waste and greenhouse emissions, as surveyed by Toyo Keizai Shimposha, and financial performance. They found that the reduction of greenhouse emissions enhanced financial performance, while waste emissions had no effect on them.

3. A Theoretical Background on the Effects of Environment Investment on Market Value

Our study investigates the relationship between environmental investment and market value, which makes it similar to some other studies in the past. However, the study makes some new contributions to the discussion as follows: First, we are able to give a more formal theoretical interpretation of why environmental investment affects markets using a resource-based view. Following Uzawa's (1969) theory on investment theory from a resource-based view, capital formation activities involve not only the purchase of capital goods but also the utilization of internal resources that have accumulated within a firm. These resources are human capital and organizational capital. Brynjolfsson, Rock and Syverson (2021) argued that when these resources are recognized as capital assets, they also contribute to market value. The market value equation based on their work is expressed as follows,

$$V_{it} = const. + a_1 TA_{it-1} + a_2 RD_{it-1} + \mu_t + v_i + \epsilon_{it} \quad (1)$$

In Equation (1), V_{it} is the market value of firm *i* at time *t*, TA_{it-1} is a tangible asset of firm *i* at time *t-1*, and RD_{it-1} is R&D assets of firm *i* at time *t-1*.

In our study, we divide R&D assets into two types: one is R&D for environmental improvements (ERD), and the other is other kinds of R&D assets (Other R&D). From the standard theory of investment, each coefficient in Equation (1) represents the cost associated with accumulating the corresponding asset. When firms incur higher associated costs for capital formation, they contribute to higher market value through productivity improvements in the long run. Hence, this theory developed by Brynjolfsson, Rock and Syverson (2021) is consistent with Hart (1995) and Porter and van der Linde (1995), because intangibles related to environmental investments contribute to market value over time. This theory gives clearer explanations for the empirical results of Dong, Vagnani and Liu (2023) who argued that environmental innovations contribute to better financial performance in the long run, though they are negative in the short-run.

The second new contribution of our study is that we use the data related to environmental activities, which is consistent with the above theory. When we estimate Equation (1) following Brynjolfsson, Rock and Syverson (2021), the source of the R&D asset related to environmental improvements should be consistent with other R&D assets and tangible assets. In our study, we obtain data on R&D related to environmental improvements, as well as other R&D from the same data source: *Survey on Research and Development* published by the Ministry of Education, Culture, Sports, Science and Technology. Although the accumulated patent data used in Colombelli, Ghisetti and Quatraro (2020) and Tian, Dong, Vagnani and Liu (2023) are close proxies to explanatory variables in Equation (1), our data provide strong variables for estimating Equation (1).

4. Data

The present study draws data on corporate R&D investments in environmental fields and technology trade values from secondary use of the official statistics of the Ministry of Internal Affairs and Communications' *Survey of Research and Development* (SRD)[1]. The SRD conducts surveys to companies and other entities on their research activities, including internal R&D investments and R&D investments by specific purpose (e.g., environmental fields). These surveys are conducted in accordance with the Frascati Manual (OECD). The SRD selects companies for the surveys based on their capital, and companies between ¥10 million and ¥100

[1] SRD provides the following example of what is included in the environmental field: "In addition to natural science research aimed at protecting the natural environment and countering environmental pollution, it also includes humanities and social science research related to environmental issues such as environmental taxation, urban planning, and social systems (e.g., waste collection). It broadly encompasses technologies related to so-called energy conservation."

million of capital are included in the sample. Companies with capital of ¥100 million or more are surveyed exhaustively. The survey was started in 1953, but electronic data derived from the Statistics Act became accessible beginning with the 1984 survey. R&D investments, including those in the environmental field, were previously examined in the 1984 survey and have been continuously surveyed since that time.

Although individual record data from the SRD can be electronically accessed under the Statistics Act starting from the 1984 survey, the creation of panel data at the firm and annual levels only became possible from the 2002 survey (which covers the actual year 2001). Beginning with the 2002 survey, a unique identifier, designated as the "Science Code," was assigned to each respondent, enabling the construction of panel data at the firm level. This study organizes the individual SRD survey data into panel data at the enterprise level using the Science Code. The period covered by this study spans from the 2002 survey to the 2022 survey (covering data from 2001 to 2021).

Figure 1 shows the trend in real environmental R&D expenditures per manufacturing company and the proportion of environmental R&D expenditures to the total R&D expenditures from 2001 to 2021. The environmental R&D expenditures per company, shown as a bar graph, have been on an upward trend throughout the entire period. Environmental R&D expenditures, which stood at approximately ¥60 million in 2001, fluctuated around ¥100–120 million in 2007 and 2013–2016, reaching ¥160 million by 2021. This represents a significant increase over the 21-year period. It suggests that manufacturing companies have demonstrated a sustained and intensifying investment stance towards the development of environmental technologies.

Concurrently, the ratio of environmental R&D expenditures to the total R&D expenditures, as depicted in the line graph, has also shown a long-term upward trend. The proportion, which stood at approximately 3.4% in 2001, gradually increased thereafter, reaching the 6% range in the late 2000s and around 7% by 2014. From 2015 onwards, it fluctuated around 7%, showing a somewhat flat trend. By 2021, it had surged sharply to nearly 10%.

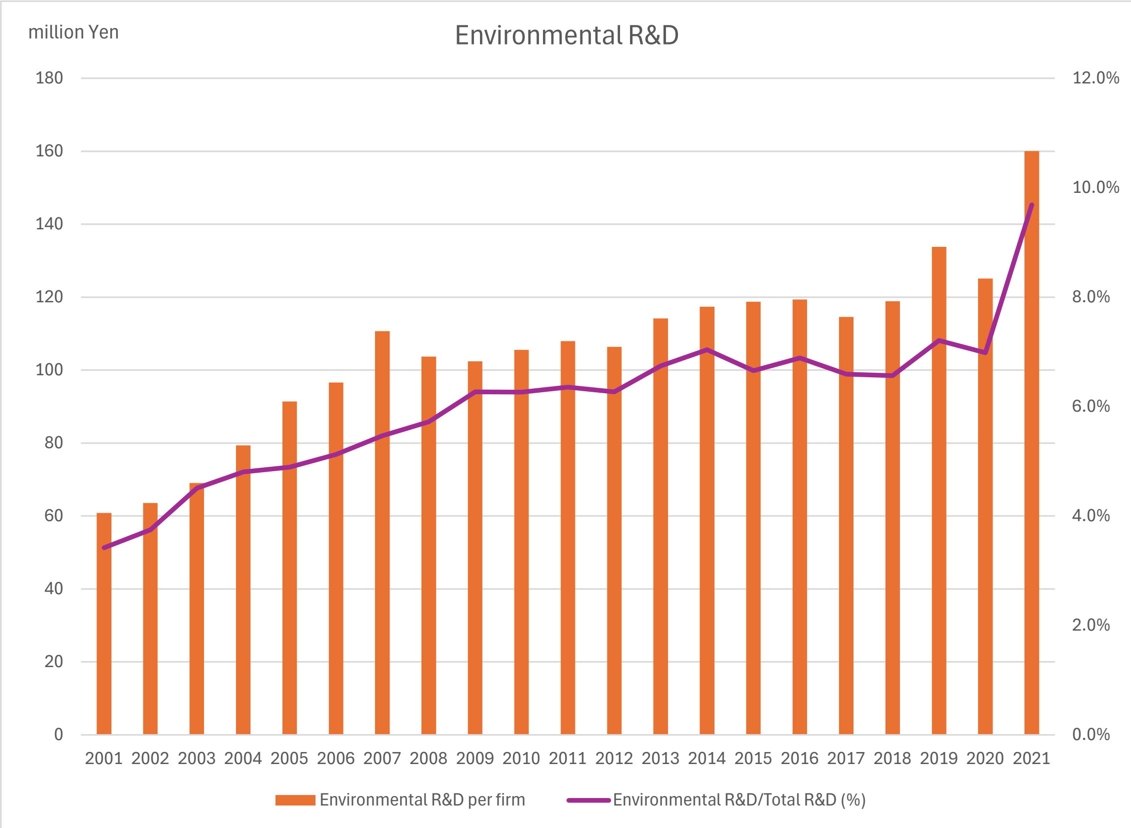

Figure1 Movements of Environmental R&D
(Source) Ministry of Internal Affairs and Communications, Government of Japan, Report on the Survey of R&D

Figure 2 presents environmental R&D in the manufacturing sector across various industries as of 2021, viewed from three perspectives. These are: environmental R&D expenditure per company by industry; the ratio of environmental R&D expenditures relative to the total R&D expenditures by industry; and the growth rate indicating the extent to which environmental R&D expenditure expanded or contracted over the 21-year period from 2001 to 2021. First, examining environmental R&D expenditures per company reveals significant variation across industries. While these amounts are very small in many industries, ranging from zero to several millions of JPY, certain industries such as "Motor vehicles," "Pottery," and "Electrical devices and parts" show exceptionally high figures. Particularly in "Motor vehicles," environmental R&D expenditures are notably higher than those in other sectors, suggesting that environmental technology development is closely linked to the industry's competitiveness. Furthermore, relatively high level of environmental R&D expenditures is also observed in industries strongly associated with environmental impacts, such as "Cement products," indicating a strong demand for environmental R&D tailored to specific industrial characteristics.

The ratio of environmental R&D expenditures relative to the total R&D expenditures also varies significantly across industries. Notably, sectors like “Motor vehicles,” “Pottery,” and “Cement” exceed 18%, suggesting environmental considerations are integrated into product development. Conversely, many industries remain below 5%, indicating that technological characteristics within the industrial structure and the strictness of environmental regulations influence relative importance.

Finally, the average growth rate from 2001 to 2021 shows significant differences across industries. Industries like “Pottery,” “Glass,” and “Textile products” show increases exceeding 10%, indicating a long-term expansion in environmental R&D investment. Conversely, many industries exhibit negative growth rates, suggesting a relative contraction in environmental R&D spending or a shift in corporate focus to other areas.

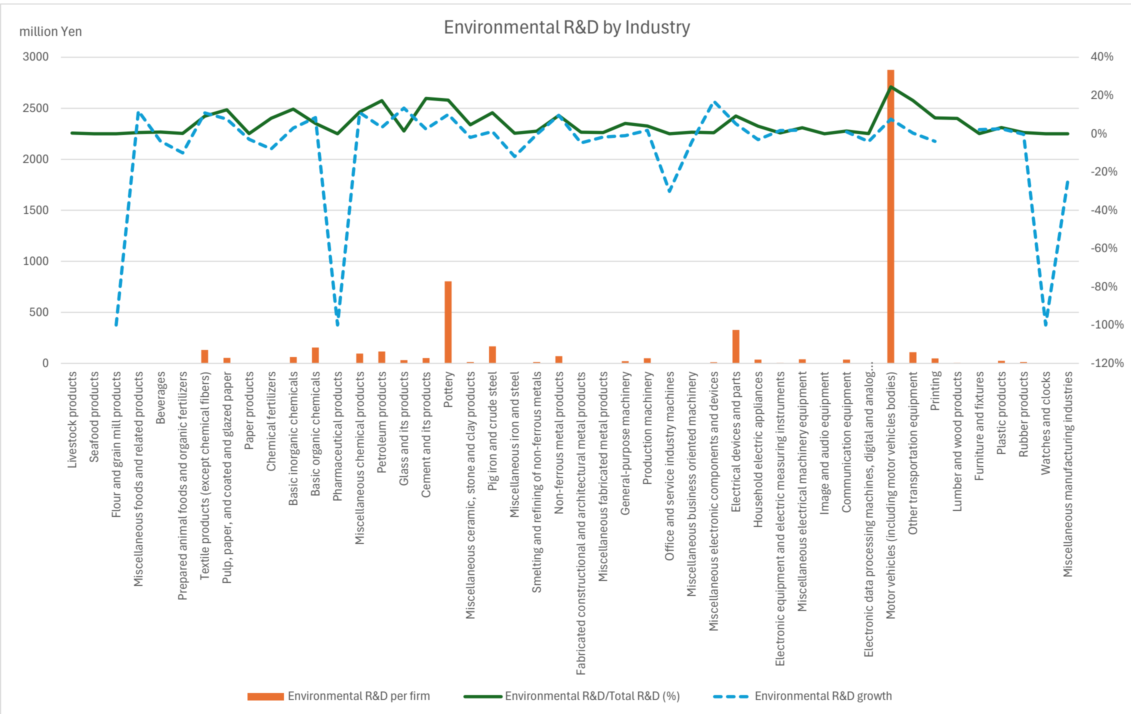

Figure2 Environmental R&D by industry

Source: Ministry of Internal Affairs and Communications, Government of Japan, Report on the Survey of R&D

For analysis, the panel data at the company level is utilized to calculate the stock of R&D investments in the environmental field. The R&D investments for the 2001 actual year, for which panel data is available, are used as the initial value. The R&D deflator employed in the

Japan Industrial Productivity (JIP) database[2] and the R&D depreciation rate of 15.76% are applied using the obsolescence rate. The stock is calculated using the perpetual inventory method.

The variables of firm value, tangible fixed assets, industry sector, number of employees, and capital amount are extracted from NEEDS-Financial QUEST (NEEDS). For publicly-traded companies, data on their stock price highs and lows, number of shares issued, total liabilities, and tangible fixed assets from 2001 to 2021 are extracted. Enterprise value is calculated as follows:

$$V_{it} = P_{it} \times NOSH_{it} + TL_{it}$$

where P_{it} is the average of the highest and lowest stock prices for company *i* in year *t*, *NOSH* is the number of shares outstanding, and *TL* is total liabilities.

To facilitate the analysis of R&D investments in conjunction with financial data, the extracted data from SRD and NEEDS are matched using cleaned company names. The company value data, which serves as the dependent variable, is given priority. SRD is linked to NEEDS in this process. It is worth noting that NEEDS has six companies with identical names. To facilitate a unique comparison with SRD, these six companies have been excluded from the sample. Table 1 summarizes the trends in NEEDS, SRD, and the number of matched companies. Figure 3 shows a graph organizing matched samples and their proportions by industry. A significant proportion of the listed companies, approximately half, were matched with the SRD.

Table 1 The number of firms

[2] The JIP database is the database for measuring productivity by industry. The database is can be found at the website for the Research Institute of Economy, Trade and Industry (https://www.rieti.go.jp/jp/database/jip.html).

year	NEEDS	SRD	Matched
2001	2502	9692	1076
2002	2569	9471	1075
2003	2598	10009	1091
2004	2625	9621	1082
2005	2659	10285	1172
2006	2696	10363	1225
2007	2736	10143	1217
2008	2778	10614	1246
2009	2807	10511	1288
2010	2819	10062	1295
2011	2831	10951	1417
2012	2,911	10,605	1461
2013	3,003	10,551	1456
2014	3,088	10,479	1504
2015	3,177	10,433	1532
2016	3,275	10,831	1630
2017	3,372	10,883	1,687
2018	3,493	10,820	1,773
2019	3,616	10,371	1,720
2020	3,732	10,805	1,784
2021	3,875	11,536	1,947
	63,162	219,036	29,678

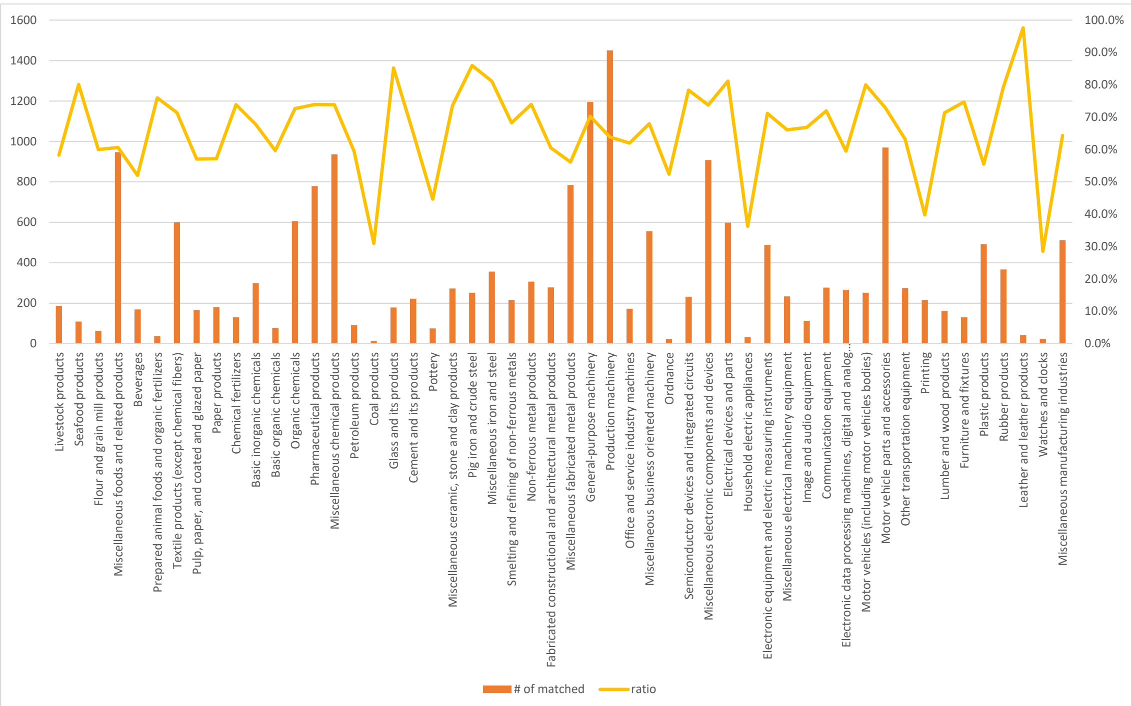

Figure3 number of matched samples and ratio by industry
Sources: Ministry of Internal Affairs and Communications, Government of Japan, Report on the Survey of R&D and NEEDS=financial QUEST

The deflators used to generate real R&D investments are obtained from the JIP Database. We create a concordance between the industry classifications in NEEDS and those in the JIP database to match the R&D deflators to the industry classification in NEEDS.

5. Estimation Method and Results

We estimate a modified version of Equation (1) using firm-level panel data from Japan's manufacturing sector from 2001 to 2021. Our modified equation, RD_{it-1} focuses on environmental R&D assets (ERD) and other types of R&D (Other R&D). To account for firm heterogeneity, we employ a fixed-effects model considering the AR1 process of error term [3]. Furthermore, to capture industry-specific and year-specific shocks, we include cross-dummy variables for industry and year in the estimation.

Table 2 presents descriptive statistics for market value, environmental R&D stock (ERD), other types of R&D (Other R&D), and tangible assets (TA). The sample size is N = 19,367, with values expressed in millions of JPY. The mean market value is 352,675 millions of JPY, with a standard deviation of 1,787,974 millions of JPY. The minimum and maximum market values are 353 millions of JPY and 73,212,871 in millions of JPY, respectively. The mean ERD is 2,624 millions of JPY, with a standard deviation of 47,926 millions of JPY. The minimum and maximum ERDs are 0, and 1,921,384 millions of JPY, respectively. The mean for Other R&D is 25,952 in millions of JPY, with a standard deviation of 128,621 millions of JPY. The minimum is 0, and the maximum is 3,258,496 millions of JPY. All exhibit extremely high variance relative to their means and long right-tailed distributions. ERD and Other R&D include zero observations, indicating a certain number of non-investment cases. To account for scale heterogeneity, the sample was divided into groups based on firm size and estimates were calculated separately.

Table 2 Basic Statistics

[3] We show estimation results by a panel GMM model to account for endogeneity in the Appendix The estimation result using all samples fails diagnostic tests, such as the AR and Hansen tests. However, when we divide all samples into firms with technological trade and those without technological trade, estimation results satisfy diagnostic tests, As the coefficients of environmental R&D are positive and significant in the case of all samples and samples focusing on firms with technological trade, the GMM estimations support our estimation results using fixed estimations with AR1.

	Mean	Std. dev.	Min	Max
N=19367	Mean	Std. dev.	Min	Max
market value	352675	1787974	353	73212871
ERD	2624	47926	0	1921384
Other R&D	25952	128621	0	3258496
TA	77443	349908	2	11743623

unit: million Yen

Estimation employs a fixed-effects model that explicitly assumes AR(1) as a panel data model with autocorrelation in the error term. In panel data analysis of firms, variables such as sales, investment, and R&D expenditures are often influenced by the previous year's levels, and the residuals tend to exhibit inherent persistence over time. Applying a standard fixed-effects model to such data may lead to overestimation of the variance of the estimated coefficients or to the erroneous conclusion that the effects of firm-specific characteristics are not statistically significant. Therefore, a model that explicitly treats autocorrelation as a structural feature is adopted.

Table 3 presents the estimation results for the full sample. The environmental R&D stock exhibits a statistically significant positive coefficient, suggesting that accumulated R&D investment in the environmental field enhances corporate value. In other words, developing and possessing environmental technologies is not merely a cost, but rather, it is viewed positively in capital markets. Furthermore, other types of R&D (Other R&D) and tangible assets (TA) also exhibit statistically significant positive coefficients. These results suggest that accumulating tangible and intangible assets increases corporate value. According to Brynjolfsson, Rock and Syverson (2021), an estimated coefficient of explanatory variables shows the degree of contribution of each asset. According to this argument, high value of coefficients of ERD shows that environmental R&D expenditures contribute to firm value more than tangible assets and other R&D expenditures in the long-run.

Table 3 Regression result (1)

	[1]
ERD	11.01459***
	(0.47682)
Other R&D	0.83860***
	(0.18488)
TA	3.50476***
	(0.06156)
_cons	44918.77844***
	(2251.60682)
Observations	19367
Number of firms	1192
Adjusted R-squared	0.24335

Note: *** p<0.01

As explained in Introduction, firms' incentives to R&D activities are affected by the company's engagement in technology trade. For companies that are engaged in this trade, technologies have the opportunities to generate external revenue through licensing and technology exports. Furthermore, by utilizing external technologies based on the absorptive capacity cultivated through their own R&D, companies can integrate complementary knowledge and expand innovation outcomes.

The impact of environmental R&D investment on corporate value is contingent on several factors. When incorporated into market expansion and external interactions, the effects of such investment may be more pronounced. Conversely, for firms not engaging in technology trade, the benefits of environmental R&D investment are primarily confined to internal regulatory compliance and efficiency gains, resulting in relatively limited effects.

Based on the above arguments, we examine whether environmental R&D activities in firms engaging in technology trade contribute to firm value more than those in firms not engaged in technology trade. Therefore, we divide our sample into two groups: firms engaging in technology trade and firms not engaging in technology trade. In the case of environmental technologies, required environmental technologies depend on the regulations in countries where firms trade with. Hence, the samples of the following estimations are selected by areas where environmental regulations are different.

The basic results of this study where samples are divided by only technology trade are summarized in Table 4. They suggest that the impact of environmental R&D stock on firm value varies significantly depending on this element.

First, for firms engaging in technology exports, environmental R&D stock has a statistically significant and positive effect on firm value. Conversely, for firms not exporting technology, the regression coefficient is not statistically significant. This outcome likely indicates that exporting firms are able to translate research and development investment outcomes into augmented revenue opportunities through the external licensing of proprietary environmental technologies.

Second, for firms engaging in technology imports, environmental R&D stock shows a significant positive impact on corporate value. This finding suggests that the incorporation of external technological resources enhances a firm's internal R&D outcomes. It increases its absorptive capacity and accelerates the practical application and commercialization of environmental technologies. Conversely, for firms not importing technology, this complementary effect is absent, making it more difficult for investment outcomes to be fully reflected in corporate value.

Third, analysis of the firms engaging in technology trade, either exports or imports, shows an even stronger effect of environmental R&D stock on firm value. This finding indicates that firms engaging in external networks through technology trade (in the context of global demand for environmental technologies and shared regulatory compliance requirements), have greater capacity to effectively monetize their environmental R&D investments.

In summary, environmental R&D investment does not necessarily enhance corporate value for all firms; its effect appears to be determined by whether a firm participates in the international technology market. Specifically, environmental R&D investment has been shown to have a statistically significant impact on corporate value for firms engaged in technology trade, while its effect is comparatively negligible for firms not involved in such trade.

Table 4 Regression result (2)

	[2]	[3]	[4]	[5]	[6]	[7]
	Tech export		Tech import		Tech export/import	
	Yes	No	Yes	No	Yes	No
ERD	9.77850***	3.81134	10.03470***	9.9031	9.81175***	13.11571
	(0.59039)	(21.06979)	(0.68181)	(25.06531)	(0.55670)	(30.55272)
Other R&D	0.72938***	17.23238***	0.34584	1.42955***	0.75963***	23.08479***
	(0.25226)	(1.45206)	(0.35177)	(0.15960)	(0.23764)	(2.00186)
TA	3.72884***	0.30642	3.76179***	2.33846***	3.71736***	0.1723
	(0.08522)	(0.22758)	(0.10133)	(0.10808)	(0.08000)	(0.27107)
_cons	51541.41154***	23159.80796***	69381.39408***	84638.73987***	45369.89117***	2619.06659
	(5364.18210)	(1588.87462)	(7822.61601)	(1217.98644)	(4616.81245)	(1845.01185)
Observations	9139	7565	7032	9680	10404	6297
Number of firms	589	593	454	721	678	506
Adjusted R-squared	0.3155	-0.06286	0.31108	-0.01596	0.31238	-0.06317

Note: *** $p<0.01$

Next, we select areas where firms trade with. Tables 5 present results from dividing the sample into companies that engage in technology trade (export or import) in the following categories: developed countries and countries with environmental regulations stricter than those of Japan[4]. First, for firms engaged in exports and/or imports with developed countries, ERD shows a positive statistical effect on corporate value. The Other R&D coefficient is also statistically significant, indicating that environmental R&D and other types of R&D assets both contribute reliably to firm value.

We examine the estimation results for a sample of companies that engage in technology trade with countries that have stricter environmental regulations than Japan. The stringency of environmental regulations is measured using the method in the OECD's *Measuring Environmental Policy Stringency in OECD Countries*. This measure quantifies the stringency of environmental regulations by country and year. Using this, we identified countries with stricter environmental regulations than Japan and extracted the group of companies engaged in technology trade with these countries.

For firms engaging in exporting and/or importing technology with countries that have stricter regulations than Japan, the ERD coefficient is positive and statistically significant. This indicates that an increase in environmental R&D stock boosts firm value for this group of firms. The Other R&D coefficient is also positive and statistically significant, suggesting that assets contribute to corporate value creation.

In summary, the estimation results from splitting the sample by firms engaging in technology trade versus those not, as well as by technology trade partner, reveal that the impact of environmental R&D stock on corporate value varies greatly depending on these factors. For technology exporting firms, environmental R&D stock consistently shows a statistically significant positive effect. This suggests that supplying environmental technology to overseas markets transforms R&D investment into revenue opportunities that are reflected in firm value. This effect is particularly evident in exports to developed countries and countries with stricter environmental regulations than Japan. This can be interpreted as regulatory compliance and market demand enhancing the economic valuation of R&D outcomes.

Meanwhile, environmental R&D (ERD) is also statistically significant for technology-importing firms, suggesting that the complementary relationship between imported technology and in-house R&D may elevate corporate value. The introduction of external technology is believed to improve a firm's absorptive capacity (Cohen & Levinthal, 1990), thereby accelerating the commercialization and market adaptation of environmental technologies.

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[4] We obtain similar results when the estimation is conducted using the subsample of firms that engage in technology exports or in technology imports.

Notably, the coefficient is much larger for imports from G7 countries, the EU, and countries with strict regulations. This suggests that integration with advanced, international environmental technologies contributes to the enhancement of corporate value in a statistically significant way.

Furthermore, analysis of firms engaged in exports, imports, or both consistently shows a stable, positive, and statistically significant ERD effect. This indicates that participation in technology trade itself supports the monetization of R&D investments. Firms more active in international technology markets may be able to more efficiently utilize their environmental R&D and translate it to corporate value.

Overall, the effects of environmental R&D investment are not universal. Certain aspects only become apparent and are amplified through international technology transactions. Specifically, companies that engage in imports or exports with countries that have stringent environmental regulations or advanced markets are likely to maximize the utilization of their environmental R&D outcomes to enhance corporate value.

Table 5 Regression result (3)

	[8]	[9]
	Technology export/ import with developed countries	Technology export/ import with countries with stricter environmental regulations
	Yes	Yes
ERD	9.76533***	9.73072***
	(0.59634)	(0.64946)
Other R&D	0.74568***	0.73609***
	(0.25459)	(0.27731)
TA	3.73173***	3.74185***
	(0.08590)	(0.09379)
_cons	53882.15436***	63526.24726***
	(5488.19327)	(6794.71175)
Observations	9045	7592
Number of firms	590	487
Adjusted R-squared	0.31336	0.31515

Note: *** p<0.01

Finally, we examine whether our empirical hypothesis depends on firm size. Table 6 shows the estimated results of categorizing manufacturing companies by enterprise size, based on capital and number of employees. Samples were divided into three groups based on capital: the top 25% (cap1), middle 50% (cap2), and bottom 25% (cap3). Groups based on employees were similarly divided into the top 25% (emp1), middle 50% (emp2), and bottom 25% (emp3). Each was estimated using a fixed-effects AR(1) model. Regarding capital and employees size, the coefficient for environmental R&D stock (ERD) is positive and statistically significant for large firms in the top 25% (cap1 and emp1). This indicates that environmental R&D investment increases the value of relatively large companies. Conversely, for firms in the middle 50% and bottom 25%, the ERD coefficients are not statistically significant (cap2, cap3, emp2, and emp3).

Overall, estimation results based on firm size, measured by both capital stock and employee count, indicate that the impact of environmental R&D investment on firm value differs markedly between large and small/medium-sized enterprises. For large firms, by both measures of size, environmental R&D stock consistently led to statistically significant increases in corporate value. This stems from large firms' ability to leverage their abundant financial and human resources to commercialize environmental R&D outcomes, making the monetization of environmental technology investments relatively easier. Additionally, large firms generally publish financial reports more frequently than SMEs, which makes sustainability evaluations by investors and consumers more likely to directly impact corporate value.

Conversely, environmental R&D stock does not necessarily have a positive effect on corporate value for SMEs. SMEs struggle to realize economies of scale and R&D scale advantages. Because the commercialization of research outcomes takes time, it is difficult for environmental R&D investments to be reflected immediately in corporate value. Furthermore, compared to large firms, constraints on external financing for SMEs may hinder monetization of environmental R&D.

Table 6 Regression result (5)

	cap1	cap2	cap3	emp1	emp2	emp3
	Capital			employment		
	Q1	Q2&Q3	Q4	Q1	Q2&Q3	Q4
ERD	10.84403***	-3.56258	-6.11013	11.01284***	4.99311	-13.46466
	(0.85442)	(13.08235)	(15.46064)	(0.62262)	(4.89388)	(17.78452)
Other R&D	0.88333***	-6.85872***	34.08560***	0.82842***	17.18738***	3.57808
	(0.33532)	(0.60794)	(1.22647)	(0.24150)	(0.72313)	(2.22685)
TA	3.52379***	2.27918***	1.31254**	3.50705***	1.04635***	-0.02606
	(0.11224)	(0.27536)	(0.55288)	(0.08043)	(0.23328)	(0.64443)
_cons	118099.22314***	97959.80676***	-32155.86664***	77581.72119***	-13197.22538***	10473.36539***
	(10331.61068)	(1362.39940)	(880.18106)	(4351.11836)	(526.20323)	(794.98407)
Observations	5488	9710	4169	11279	7804	284
Number of firms	322	582	288	663	498	31
Adjusted R-squared	0.26508	-0.04332	0.11094	0.24644	0.01488	-0.11654

Note: *** $p<0.01$, ** $p<0.05$.

6. Concluding Remarks

The contributions of private firms to addressing environmental issues are difficult to measure, because goods and services derived from natural resources are invisible. In addition, as they have externalities, we are not able to specify the benefits from environmental activities by private firms. Although the natural-resource view developed by Hart (1995) and Porter and van der Linde (1995) argued that the accumulation of environmental activities can enhance the competitive advantages of firms, it does not account for the firm's incentives to engage in environmental activities. We address this gap by applying the arguments developed by Brynjolfsson, Rock and Syverson (2021) to environmental issues. Their arguments suggest that environmental investment contributes to firm value, when costs associated with environmental investment accumulate as intangibles within a firm. This explanation is consistent with the standard theory of investment.

Drawing on the firm value function developed by Byrnjolfsson, Rock and Syverson (2021), we examine the impacts of environmental R&D on firm value. Our estimation results are summarized in the following three points. First, across the full sample, we find a coefficient of environmental R&D that is positive and significant on firm value and whose contribution exceeds that of all other assets. Second, with our sample divided into firms engaging in technology trade and not engaging in technology trade, environmental R&D has positive and significant impacts on firm value only for firms engaging in technology trade. Third, regarding firm size, we found that environmental R&D exerts a positive and significant impact on firm value for large-scale firms.

While the estimation results of the full sample support previous empirical findings on private firms, our estimations show that positive impacts of environmental R&D are confined to specific categories of firms. The second and third estimation results indicate that only large-scale firms or firms engaging in technology trade aggressively pursue environmental R&D activities. This implies that policies supporting all environmental activities are not effective. Consequently, the government should develop environmental technology that will be adopted by firms that are less active in trade or SMEs. In addition, following the US withdrawal from the Paris Agreement, the private financial sector has become reluctant to finance environmental activities. If the Japanese government keep to be committed to the Paris Agreement, they should also support R&D related to environmental improvements more from the financial side.

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Appendix 1 Estimation Results Using the GMM

Table A1-1 estimation results (1)

sample: manufacturer	gmm1
	GMM
ERD	2.75343***
	(0.81497)
Other R&D	0.2033
	(0.40650)
TA	0.53479
	(0.43768)
L.marketvalue	0.82331***
	(0.06405)
Year D	Yes
Observations	18572
Number of firms	1187
AR(1)	-1.0887
AR(1) p	0.27628
AR(2)	-1.5294
AR(2) p	0.12617
Hansen	1152.83504
Hansen p	0

Note: *** p<0.01.

Table A1--2 estimation results (2)

sample: manufacturer	gmm1	gmm2	gmm3	gmm4	gmm5	gmm6
tech trade	Technology export		Technology import		Technology export/ import	
	Yes	No	Yes	No	Yes	No
ERD	3.16060***	-12.29104	3.26221***	-0.40041	3.12967***	-17.33254
	(0.73914)	(10.75545)	(0.76249)	(9.44292)	(0.75183)	(22.26114)
Other R&D	-0.06248	7.19202**	-0.18224	1.16013***	-0.04415	8.45977*
	(0.37039)	(3.50356)	(0.34889)	(0.18740)	(0.37446)	(4.90310)
TA	0.70620*	-1.05240**	0.60774	-0.34219	0.70973*	-1.18795**
	(0.40764)	(0.41817)	(0.45145)	(0.53903)	(0.40848)	(0.47587)
L.market value	0.78589***	1.11155***	0.80636***	0.99266***	0.78619***	1.11396***
	(0.05297)	(0.05335)	(0.05622)	(0.13560)	(0.05343)	(0.06355)
Year D	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8761	7247	6724	9284	9972	6036
Number of firms	591	592	456	721	680	506
AR(1)	-0.80742	-1.23342	-0.85967	-1.24731	-0.81383	-1.1942
AR(1) p	0.41943	0.21742	0.38997	0.21228	0.41575	0.2324
AR(2)	-1.46514	-0.83414	-1.33816	-1.35498	-1.47012	-0.79255
AR(2) p	0.14288	0.4042	0.18084	0.17542	0.14153	0.42804
Hansen	573.03834	582.52158	446.6335	691.68287	657.08626	501.01015
Hansen p	1	0.99999	1	0.88769	0.98503	1

Note: *** p<0.01, ** p<0.05, * p<0.1.