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# Firms' reduction of greenhouse gas emissions and economic performance: analyzing effects through demand and productivity

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## Keywords

Reduction of greenhouse gas emissions; Economic performance; Increase in demand; Improvement in productivity; Instrumental variables model

## Abstract

This paper analyzes how a firm's reduction of its greenhouse gas (GHG) emissions affects its economic performance. The theoretical model used is derived from the Cobb–Douglas production function and the inverse demand function, and predicts that in reducing its GHG emissions, a firm will increase its value added because it promotes an increase in demand for its output and improves its productivity. The estimation results, using data on Japanese manufacturing firms, suggest that the reduction of GHG emissions increases a firm's economic performance only through an increase in demand. Thus, firms can improve their overall economic performance because increased demand accompanies their reduction of GHG emissions, even if they cannot achieve this through an improvement in productivity, as estimates here support the traditional view that reducing GHG emissions imposes additional costs on firms.

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## 1. Introduction

Emissions of greenhouse gases (GHGs), especially of carbon dioxide, which contributes to global warming, are regarded as one of several major environmental concerns. In the approaching post-Kyoto Protocol era, the importance of the issue will become more obvious. Nevertheless, the private sector in Japan has tended to increase its GHG emissions continuously (Ikkatai et al., 2008). Hence, to mitigate climate change, it is necessary need to ensure reductions of GHG emissions, especially by industry sectors whose energy-intensive production usage involves emission of significant quantities of GHGs (Bernstein et al., 2007; Bradford and Fraser, 2008). Indeed, carbon dioxide emissions from fuel combustion in industries accounted for 26.2% of Japan's total GHG emissions in the country's fiscal year (FY) 2008 (Greenhouse Gas Inventory Office of Japan, 2010)[1]. In these circumstances, despite the need for policy intervention to ensure firms reduce their GHG emissions, the policy mix combining direct regulation (e.g. emission control and energy consumption regulations) and indirect regulation (e.g. deposit–refund systems, charges and taxes, emissions trading, and financial assistance) has not functioned effectively (Dawson and Segerson, 2008; Iwata et al., 2010; Murase, 2003). An alternative approach by policymakers has been to attempt to encourage firms to reduce their GHG emissions voluntarily rather than compulsorily via regulation (Ikkatai et al., 2008).

However, it is widely believed that firms will adopt voluntary initiatives only if the benefits of voluntarism outweigh the costs, and if the payoff is not as high as it would be without their engagement in such activity. Therefore, if there is a negative trade-off between a firm's reduction of its GHG emissions and its economic performance, firms will not voluntarily reduce their GHG emissions (Porter and Linde, 1995a; Segerson and Miceli, 1998; Welch et al., 2000, 2002). The traditional view is that the reduction of GHG emissions imposes additional costs on firms, and this is still a deep-rooted belief in the business sector (Newell, 2010; Pinkse and Kolk, 2010). However, environmentally proactive firms no longer ask how much the reduction of GHG emissions will cost, but rather how much it will benefit them (Cogan, 2006; Kolk et al., 2008). If there is a positive relationship between firms' reduction of GHG emissions and their economic

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[1] Carbon dioxide emissions in Japan in FY 2008 were 1,214 million tons, accounting for 94.7% of the country's total GHG emissions. The breakdown of carbon dioxide emissions by source shows that fuel combustion is the largest source, accounting for 94.9%. When carbon dioxide emissions from fuel combustion are further broken down by sector, the energy sector accounts for 36.4%, the industry sector for 29.2%, the transport sector for 19.8%, and other sectors for 14.6%.

performance, it would be reasonable to encourage firms to reduce their GHG emissions voluntarily, because this approach is expected to be more flexible and effective, and less costly, than direct and indirect regulations (Arimura et al., 2008). If this is not the case, however, a new environmental policy mix should be introduced.

Although few studies have focused on the reduction of GHG emissions, many previous empirical studies (reviewed in Section 2) have found that firms improve their economic performance through better environmental activities and performance. According to these studies, the positive effect of environmental activities and performance on economic performance generally results from an increase in demand and improvement in productivity (Khanna, 2001; Khanna et al., 1998). Better environmental performance provides positive information about environmentally friendly firms and their products to the public, thus enabling firms to increase their market share and/or charge higher prices for their products. By contrast, poor environmental performance is seen as reflecting poor management practices and a lack of innovativeness in taking up the potential cost savings available by reducing environmental impacts[2]. If this argument applies to the reduction of GHG emissions, such benefits directly and indirectly depend on a firm's skills in reducing GHG emissions; such skills include hedging against physical climate risk, mitigating regulatory costs, avoiding expensive litigation and other threats to corporate reputation, managing climate risk in the supply chain, investing capital in low-carbon assets, and innovating around new technology and product opportunities (Lash and Wellington, 2007). Thus, firms that successfully seek opportunities for profit would generate a competitive advantage over rivals through plural paths (Lash and Wellington, 2007). To mitigate global warming, it is important to understand accurately how firms' voluntary behavior in relation to reducing GHG emissions affects their economic performance.

Therefore, the purpose of this study is to analyze whether the reduction of GHG emissions improves a firm's economic performance through an increase in demand and/or an improvement in productivity. To achieve this purpose, this paper applies a simple theoretical model derived from a Cobb–Douglas production function and the inverse demand function to identify how these effects influence a firm's economic performance, as proposed by Nishitani (2011), and estimates these parameters using cross-sectional data for Japanese manufacturing firms in 2007.

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[2] In addition, poor environmental performance is viewed as exposing the firm to greater risks of environmental liabilities, penalties, and high costs of compliance in the future.

The main findings are as follows. If all firms are regarded as homogeneous, reducing GHG emissions enhances a firm's economic performance only if demand for its products increases. Even if firms are regarded as heterogeneous in terms of industry, positive effects through an improvement in productivity are not observed, whereas many industries show benefits from an increase in demand attributable to their emission reductions. However, although negative effects through declines in productivity are observed in several industries, firms that reduce their GHG emissions may at least acquire a net competitive advantage from increases in demand for their output.

This paper is divided into the following sections. Section 2 reviews the literature on the relationship between firms' environmental and economic performance. Section 3 describes a theoretical model of the effect of the reduction of GHG emissions on a firm's economic performance. Section 4 presents details of the data. Section 5 provides the results of the estimations. Finally, Section 6 presents some concluding remarks.

## 2. Literature review

Many empirical studies have analyzed whether a firm's environmental performance improves its economic performance in order to confirm whether the relationship between them is positive or negative. Such studies generally examine this relationship based on the following hypotheses: 1) better (worse) environmental performance increases (decreases) stock market performance, and 2) better (worse) environmental performance increases (decreases) financial performance.

In the latter part of the 1990s, for example, Hamilton (1995), using an event study with data on US firms with toxic release inventory (TRI) emissions, found a relationship between TRI announcements and negative abnormal returns. Hart and Ahuja (1996), using a multiple regression analysis with data for 1989–1992 from the Investor Responsibility Research Center's Corporate Environmental Profiles, found a positive relationship between total chemical substance emission reduction and the return on sales, return on assets (ROA), and return on equities over 1–2 years. Klassen and McLaughlin (1996), using an event study with 1989 and 1990 data from the NEXIS database of newswire services, found relationships between winning an environmental award and positive stock returns and between environmental crises and negative stock returns. Cordeiro and Sarkis (1997), using ordinary least squares (OLS) with data on 512 US firms, found a negative relationship between environmental activism as measured by TRI data and industry analyst 1–5-year earnings-per-share performance forecasts. Russo and Fouts (1997), using a pooled data analysis with data on 243 firms in 1991 and 1992, found a positive relationship between environmental rating scores by the Franklin Research and Development Corporation and ROA. Yamashita et al. (1999), using an event study with data on 26 US firms, found that high environmental conscientiousness scores as published in Fortune magazine weakly increased stock returns.

In the 2000s, Dowell et al. (2000), using piecewise regressions with data on 89 firms in the US Standard and Poor's (S&P) 500 index for 1994–1997, found that firms adopting a severer global environmental standard have a much higher Tobin's q, which is defined as the market value of equity plus the book value of total liabilities, divided by the book value of total assets as a proxy for firm value. Konar and Cohen (2001), using OLS with White's heteroskedasticity-consistent standard errors on a data set of 321 firms in the S&P 500 index, found that bad environmental management performances, resulting in problems such as toxic chemical releases and environmental lawsuits, correlated negatively with firms' market value. Thomas (2001), using a pooled analysis with data on UK firms for 1985–1997, found that the adoption of an environmental policy had a significantly positive effect on corporate excess returns, while prosecution for the breach of environmental standards had a significantly negative effect. King and Lenox (2002), using a fixed effects regression with data on 614 US manufacturing firms for 1991–1996, found that pollution prevention positively influenced Tobin's q and ROA.

Gupta and Goldar (2005), using an event study with data on 50 Indian firms in the pulp and paper, automobile and chlor-alkali industries, found a positive relationship between abnormal returns to a firm's stock and the level of its environmental performance measured by the environmental rating awarded by India's leading environmental NGO, the Delhi-based Centre for Science and Environment. Darnal et al. (2007), using a bivariate probit model with data from the OECD survey of approximately 4,200 manufacturing facilities in Canada, France, Germany, Hungary, Japan, Norway, and the US in 2003, found a positive relationship between several environmental performance measures, including a decrease in wastewater effluent and air pollution, and financial benefit. Nakao et al. (2007), using a pooled data analysis with data on 121 firms in 2002 and 2003, found a positive relationship between environmental rating scores by Nikkei Inc. and Tobin's q–1. Ziegler et al. (2007), using time-series and cross-sectional regressions with data on 212 European firms for

1996–2002, found that an industry's average environmental performance has a significantly positive effect on a firm's stock market performance, whereas the relative environmental performance of a firm within a given industry does not. Yamaguchi (2008), using an event study that accounts for Generalized Autoregressive Conditional Heteroskedasticity effects with data on 69 Japanese firms for 1998–2006, found a positive relationship between environmental ratings made by Nikkei Inc. and stock prices.

In the 2010s, Hibiki and Managi (2010), using the generalized method of moments with data on 402 Japanese manufacturing firms for 2003–2004, found that the Japanese financial market does not value risk associated with toxic chemical releases as measured by the Pollutant Release and Transfer Register. Jacobs et al. (2010), using an event study methodology with data on 340 US firms, found that announcements of philanthropic gifts for environmental causes and ISO 14001 certification are associated with significant positive market reaction (abnormal returns), and voluntary emission reductions are associated with significant negative market reaction. Zeng et al. (2010), using a structure equation model with data on 125 manufacturing firms listed in the Directory of Audited Enterprises of Cleaner Production in China, found that cleaner production activities positively influence both financial and nonfinancial performance. Heras-Saizarbitoria et al. (2011), using a multivariate panel data analysis with data on 196 Spanish firms for 2000–2005, did not find that firms with ISO 14001 certification have stronger economic performance when measured by ROA and greater sales volume growth. Nishitani (2011), using a fixed effects instrumental variables (IV) model with data on 871 Japanese manufacturing firms for 1996–2007, found that the implementation of an Environmental Management System increased a firm's value added through increasing demand and improving productivity. Nishitani et al. (2011), using a random effects IV model with data on 426 Japanese manufacturing firms for 2002–2008, found that a reduction of pollution emissions increased a firm's value added through increasing demand and improving productivity, although as the latter is conditional, a prevention approach to reducing emission is preferred.

These studies generally indicate that by improving its environmental performance, a firm also improves its economic performance, despite the traditional view that there is a trade-off between them. Accordingly, the debate about whether a firm systematically derives profitable opportunities from this behavior is ongoing (King and Lenox, 2002). Thus, our question in this paper is whether this relationship is applicable to the reduction of GHG emissions. Nishitani (2011) and Nishitani et al. (2011) found that, to analyze the relationship between the reduction of GHG emissions and economic performance, especially financial performance, it is better to consider that a positive effect of environmental performance would result from a simultaneous increase in sales – following an increase in demand among environmentally conscious customers – and reduction in costs – following an improvement in productivity (Reinhardt, 1999; King and Lenox, 2002). Therefore, this study applies their approach for the reduction of GHG emissions to estimate simultaneously the effects of an increase in demand and improvement in productivity, whereas most of the above empirical studies did not distinguish between these effects.

## 3. Model

This section introduces a simple theoretical model originally specified by Nishitani (2011) to analyze how the reduction of GHG emissions influences a firm's economic performance. The economic performance in this study is measured by value added, which is total revenue minus material cost, and it is distributed through profits and wages. The regression model to estimate the effects of the reduction of GHG emissions on value added is derived from a Cobb–Douglas production function and an inverse demand function.

The Cobb–Douglas production function with labor, capital, and materials for firm $i$ is:

$$X_i = A_i L_i^{\alpha} K_i^{\beta} M_i^{1-\alpha-\beta}, \tag{1}$$

where $X$ is output, $L$ is labor, $K$ is capital, $M$ is materials, $A$ is total factor productivity, and $0 < \alpha < 1$, $0 < \beta < 1$, and $0 < \alpha + \beta < 1$.

Given total revenue $Y_i = p_i X_i$ where $p$ is the price of output, labor cost $W_i = wL_i$ where $w$ is the wage rate, capital cost $R_i = rK_i$ where $r$ is the implicit rental rate of capital, and materials cost $Q_i = qM_i$ where $q$ is the price of materials, it follows that:

$$\frac{Y_i}{p_i} = A_i \left(\frac{W_i}{w}\right)^{\alpha} \left(\frac{R_i}{r}\right)^{\beta} \left(\frac{Q_i}{q}\right)^{1-\alpha-\beta}. \tag{2}$$

The inverse demand function,

$$p_i = aX_i^{-\gamma} , \tag{3}$$

yields the price, and then total revenue is expressed as follows:

$$\begin{aligned} Y_i &= a_i \left\{ A_i \left(\frac{W_i}{w}\right)^{\alpha} \left(\frac{R_i}{r}\right)^{\beta} \left(\frac{Q_i}{q}\right)^{1-\alpha-\beta} \right\}^{1-\gamma} \\ &= a_i A_i^{1-\gamma} \left(\frac{W_i}{w}\right)^{\alpha-\alpha\gamma} \left(\frac{R_i}{r}\right)^{\beta-\beta\gamma} \left(\frac{Q_i}{q}\right)^{1-\alpha-\beta-\gamma+\alpha\gamma+\beta\gamma} , \end{aligned} \tag{4}$$

where $1-\gamma > 0$. Accordingly, value added is:

$$Y_i - Q_i = a_i A_i^{1-\gamma} \left(\frac{W_i}{w}\right)^{\alpha-\alpha\gamma} \left(\frac{R_i}{r}\right)^{\beta-\beta\gamma} \left(\frac{Q_i}{q}\right)^{1-\alpha-\beta-\gamma+\alpha\gamma+\beta\gamma} - Q_i . \tag{5}$$

Because $\frac{Y_i - Q_i}{Q_i}$ is the ratio of value added to material cost, equation (5) is transformed into:

$$\frac{Y_i}{Q_i} = a_i A_i^{1-\gamma} \left(\frac{W_i}{w}\right)^{\alpha-\alpha\gamma} \left(\frac{R_i}{r}\right)^{\beta-\beta\gamma} Q_i^{-\alpha-\beta-\gamma+\alpha\gamma+\beta\gamma} q^{-(1-\alpha-\beta-\gamma+\alpha\gamma+\beta\gamma)} . \tag{6}$$

Suppose that $a_i$ and $A_i$ are functions describing the reduction of GHG emissions $RG$, and they are described as:

$$a_i = e^{\omega^{(0)}+\omega^{(1)}RG_i^{(a)}} , \tag{7}$$

where $\omega^{(1)} > 0$ is the effect of a reduction of GHG emissions that occurs through an increase in demand, and:

$$A_i = e^{\delta^{(0)}+\delta^{(1)}RG_i^{(A)}} , \tag{8}$$

where $\delta^{(1)} > 0$ is the effect of the reduction of GHG emissions that occurs through an improvement in productivity.

Taking logarithms of both sides of equation (6) and substituting equations (7) and (8) yields:

$$\ln\frac{Y_i}{Q_i} = (\alpha - \alpha\gamma)\ln W_i + (\beta - \beta\gamma)\ln R_i + (-\alpha - \beta - \gamma + \alpha\gamma + \beta\gamma)\ln Q_i + \omega^{(1)} RG_i^{(a)} + (1-\gamma)\delta^{(1)} RG_i^{(A)}$$
$$+ \omega^{(0)} + (1-\gamma)\delta^{(0)} - (\alpha - \alpha\gamma)\ln w - (\beta - \beta\gamma)\ln r - (1 - \alpha - \beta - \gamma + \alpha\gamma + \beta\gamma)\ln q\,. \qquad (9)$$

Equation (9) indicates that the reduction of GHG emissions influences a firm's value added (the ratio of value added over material cost) through an increase in demand and an improvement in productivity. Consequently, equation (9) with an error term is the regression model for estimating the parameters of the reduction of GHG emissions $\omega^{(1)}$ and $(1-\gamma)\delta^{(1)}$, where the second line of equation (9) is the constant term. Although the parameter for the effect of the reduction of GHG emissions through improvement in productivity $\delta^{(1)}$ is not directly estimated, we can calculate it from the estimated parameters because $\gamma$ can be obtained by solving the following equations: $(\alpha - \alpha\gamma) = B_1$, $(\beta - \beta\gamma) = B_2$, and $(-\alpha - \beta - \gamma + \alpha\gamma + \beta\gamma) = B_3$. The predicted signs of these parameters are positive for $(\alpha - \alpha\gamma)$, $(\beta - \beta\gamma)$, $\omega^{(1)}$, and $(1-\gamma)\delta^{(1)}$, and negative for $(-\alpha - \beta - \gamma + \alpha\gamma + \beta\gamma)$.

## 4. Data

The data used in the analysis are cross-sectional data on 685 Japanese manufacturing firms (in the food, textiles, pulp and paper, chemicals, pharmaceuticals, petroleum, rubber, glass, steel, nonferrous metals, metals, general machinery, electrical appliances, transportation machinery, precision instruments, and other manufacturing industries) listed on the Tokyo and Osaka Stock Exchanges in 2007, and that meet the reporting requirements of a mandatory GHG accounting and reporting system, based on the Law on Global Warming Countermeasures[3]. Holding companies are not included in

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[3] The sample firms include those that have facilities consuming more than 1,500 kl/year (converted into oil) of energy.

the sample. Although we did not select these 685 firms randomly, we regard them as a representative sample of all Japanese manufacturing firms. A list of the dependent and independent variables is given in Table 1, and the descriptive statistics are in Table 2. The dependent variable is the logarithm of net sales over raw materials expense as a proxy for $\ln\frac{Y}{Q}$, and the independent variables are the logarithm of wages for $\ln W$, the logarithm of the book value of tangible fixed assets for $\ln R$, the logarithm of raw materials expense for $\ln Q$, the $CO_2$ management score derived from the rank in "promotion of global warming countermeasures" as evaluated by the Nikkei Environmental Management Survey[4] for the proxy for $RG^{(a)}$ (firms are given a score depending on their rank in the survey: firms ranked between first and 500th are given a score ranging from 20 points to one point, respectively, per 25 ranks, and those ranked below 500th or unranked are given zero points), and the $CO_2$ reduction score based on the $CO_2$ reduction rate for the proxy for $RG^{(A)}$ (firms are given a score ranging from 10 points to one point, respectively, per 25% of their $CO_2$ reduction rate between the range of a reduction of more than 100% to an increase of more than 100%, which is calculated from the $CO_2$ emissions over net sales in $t$ divided by those in $t-1$).

In regard to proxying the reduction of GHG emissions, these variables are generally reasonable because of the following assumptions, although there are several other possible proxies for the reduction of GHG emissions[5]. First, the effect of the reduction of GHG emissions through an increase in demand is captured by the rank in "promotion of global warming countermeasures" in the Nikkei Environmental Management Survey. This third party's popular survey creates an image of environmentally friendly firms among customers through several media outlets such as newspapers, websites, and books. We use this proxy, because it is difficult for environmentally conscious customers to directly obtain actual GHG information on a supplier at any point of time, and therefore they refer to the announced rankings in making their consumption decisions[6]. Second, the effect of the reduction of GHG emissions through an improvement in productivity is captured by the reduction itself. This is because improving both environment and productivity can be regarded as evidence of the effectiveness and efficiency of management activities. We categorize the reduction rate and specify the

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[4] The Nikkei Environmental Management Survey, published annually by Nikkei Inc. since 1997, evaluates firms' attempts to establish an organizational structure and functions to implement environmental measures to reduce GHGs, chemical material emissions, and other waste while improving business efficiency (Nakao et al., 2007).

[5] Nishitani et al. (2011) adopt the same assumptions for the reduction of pollution emissions.

[6] The government does not release firms' actual GHG emission data until approximately 2 years after the fact.

score along with the effect through the increase in demand. The correlation between the $CO_2$ management score and $CO_2$ reduction score is 0.046, which suggests that they are not necessarily proportional.

The data for all firm-level variables with the exception of $RG$ are taken from Nikkei NEEDS. The data on rankings in relation to promotion of global warming countermeasures are from Nikkei Inc., and those for $CO_2$ emissions are from the Japanese Ministry of the Environment. We deflate all financial values using the GDP deflator.

(Table 1)

(Table 2)

## 5. Estimation results

Table 3 summarizes the estimation results. All firms are assumed to be homogeneous in Model (1), and are assumed to be heterogeneous in terms of industries in Model (2). Both estimation models are estimated using an IV model to avoid endogeneity bias derived from the theoretical model. Instruments for IV are the independent variables in $t-1$ (logarithm of wages, logarithm of the book value of tangible fixed assets, and logarithm of raw materials expense in $t-1$). The estimated model is considered adequate under the following conditions: the endogeneity test, the underidentification test (Anderson canon. corr. LM statistic), weak-identification test (Cragg–Donald Wald F statistic), and overidentification test (Sargan statistic) are all fulfilled[7].

Model (1) shows that logarithm of wages, logarithm of the book value of tangible fixed assets, and $CO_2$ management score are significantly positive, and that logarithm of raw materials expense is significantly negative. Hence, the reduction of GHG emissions enhances economic performance only through an increase in demand. Because the coefficient of $CO_2$ management score is 0.022, the marginal effect through an increase in demand is approximately 2.2% (per 25 rank increase)[8].

Model (2) includes the interaction terms of the independent variables for the reduction of GHG emissions and 16 industry dummies. The significant coefficients of

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[7] If we use the panel data for 2007–2008, these tests are not fulfilled, although a larger data set is preferable.

[8] Because the dependent variable is the logarithm of net sales over raw materials expense, we can calculate the marginal effect using the parameter exponent.

logarithm of wages, logarithm of the book value of tangible fixed assets, and logarithm of raw materials expense lead to $\gamma$ = 0.059, where $1-\gamma>0$. With respect to the reduction of GHG emissions, the coefficients of the interaction term of $CO_2$ management score and industry dummy are significantly positive in the food, chemicals, pharmaceuticals, nonferrous metals, electrical appliances, precision instruments, and other manufacturing industries, and those of the interaction term of $CO_2$ reduction score and industry dummy are significantly negative in the petroleum and nonferrous metals industries. Thus, although positive effects through an increase in demand are observed, positive effects through an improvement in productivity are not observed at the industry level. In fact, if anything, negative effects through a deterioration of productivity are observed in several industries. Because the coefficient of $CO_2$ management score is 0.029 in food, 0.027 in chemicals, 0.053 in pharmaceuticals, 0.030 in nonferrous metals, 0.029 in electrical appliances, 0.036 in precision instruments, and 0.031 in other manufacturing, the marginal effects through an increase in demand for these industries are approximately 2.9%, 2.7%, 5.4%, 3.1%, 2.9%, 3.7%, and 3.1% (per 25 rank increase), respectively. On the other hand, because the coefficient of $CO_2$ reduction score is –0.647 in petroleum and –0.218 in nonferrous metals, the marginal effects through a deterioration of productivity for these industries are approximately –49.7% and –20.6% (per 25% reduction), respectively[9].

These results suggest that although the effect(s) of reduction of GHG emissions depend(s) on the industry, there is no positive effect through an improvement in productivity.

(Table 3)

## 6. Concluding remarks

This paper analyzed how a firm's reduction of GHG emissions affects its economic performance, based on a theoretical model derived from the Cobb–Douglas production function and the inverse demand function. The model predicts that the reduction of GHG emissions increases a firm's value added through an increase in demand and improvement in productivity. The main findings are as follows.

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[9] $\delta^{(1)}$ is calculated from the coefficient of $CO_2$ reduction score divided by $(1-\gamma)$.

First, if all firms are regarded as homogeneous, the reduction of GHG emissions increases a firm's economic performance only through an increase in demand. This suggests that the reduction of GHG emissions improves economic performance by increasing demand among environmentally conscious customers. As far as the effect of the reduction of GHG emissions through an increase in demand is captured by the $CO_2$ management score, and that of the reduction in GHG emissions through an improvement in productivity is captured by the $CO_2$ reduction score, firms can improve their economic performance by an increase in demand following the reduction of GHG emissions, even in the absence of an improvement in productivity.

Second, if firms are regarded as heterogeneous in terms of their respective industries, the reduction of GHG emissions improves firms' economic performance through an increase in demand in the food, chemicals, pharmaceuticals, nonferrous metals, electrical appliances, precision instruments, and other manufacturing industries, and decreases economic performance through a deterioration of productivity in the petroleum and nonferrous metals industries. Thus, the reduction of GHG emissions could especially harm the economic performance of firms in these energy-intensive industries through a decline in their productivity (it is remarkable that their negative effects are relatively large); this is in line with the traditional view a trade-off exists between a firm's environmental and economic performance. Furthermore, no industries show a positive relationship between firms' improvement in productivity by the reduction of GHG emissions and economic performance. This constitutes a potential reason why businesses oppose voluntary GHG emission reductions, in line with the traditional view. Because most Japanese manufacturing firms have already introduced energy-efficient production processes, it would be difficult for them to improve productivity by the further reduction of GHG emissions. However, the negative effect of a reduction of GHG emissions is conditional, because an emission reduction can simultaneously improve a firm's economic performance through increasing demand. Indeed, even firms in the nonferrous metals industry that show declining economic performance because of lower productivity can simultaneously experience improved economic performance arising from an increase in demand, as can firms in many other industries.

Thus, this paper has found that firms that greatly reduce their GHG emissions can experience enhanced economic performance because there is an increase in demand for their output. This implies that the positive effect through an increase in demand is currently important for most firms that reduce their GHG emissions, at least in the short term. Therefore, even if the reduction of GHG emissions imposes additional costs on firms, it is possible that the reduction will be cancelled out by increasing demand. This finding presents a new contribution regarding GHG emissions for managers as well as policymakers. However, if a positive effect through an improvement in productivity were also expected, firms would be more active in attempting to reduce their GHG emissions, which would also be desirable for mitigating global warming. Because innovation in the production process would enhance improvement in productivity in the long term, a new policy mix to stimulate further innovation as part of the reduction of GHG emissions might be required, as the Porter hypothesis suggests that properly designed environmental policies can trigger innovations that lower the total cost of a product (Porter, 1991; Porter and Linde, 1995a, 1995b). In addition to grants-in-aid, indirect regulation such as a carbon tax and an emissions trading scheme could be appropriate, because both strategies provide firms with economic incentives to innovate for the sake of the environment.

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Table 1 Definition of variables

| Variable | Definition |
|---|---|
| Ln_value_added | Logarithm of net sales over raw material expense |

| | |
|---|---|
| Ln_labor_cost | Logarithm of wage expense |
| Ln_capital_cost | Logarithm of the book value of tangible fixed assets |
| Ln_material_cost | Logarithm of raw materials expense |
| $CO_2$ management score | The score derived from the rank in relation to promotion of global warming countermeasures as evaluated by the Nikkei Environmental Management Survey: firms are given a score depending on their rank in the survey: firms ranked between first and 500th are given a score from 20 points to one point, respectively, per 25 ranks, and those ranked below 500th or unranked are given zero points |
| $CO_2$ reduction score | The score based on the $CO_2$ reduction rate: firms are given a score from 10 points to one point, respectively, per 25% of their $CO_2$ reduction rate between a more than 100% reduction and a more than 100% increase calculated from pollution emissions in $CO_2$ over net sales in 2007 divided by those in 2006 |

Table 2 Descriptive statistics

|  | Obs. | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Ln_value_added | 685 | 1.130 | 0.693 | 0.124 | 5.816 |
| Ln_labor_cost | 685 | 8.448 | 1.291 | 3.859 | 13.315 |
| Ln_capital_cost | 685 | 9.864 | 1.309 | 5.506 | 14.086 |
| Ln_material_cost | 685 | 9.996 | 1.553 | 5.527 | 15.799 |
| Ln_labor_cost (t-1) | 685 | 8.457 | 1.271 | 3.937 | 13.336 |
| Ln_capital_cost (t-1) | 685 | 9.860 | 1.302 | 5.388 | 14.033 |
| Ln_material_cost (t-1) | 685 | 9.960 | 1.547 | 5.366 | 15.751 |
| $CO_2$_management_score | 685 | 5.225 | 6.812 | 0 | 20 |
| × Food | 685 | 0.323 | 1.831 | 0 | 15 |
| × Textiles | 685 | 0.093 | 1.026 | 0 | 13 |
| × Pulp and paper | 685 | 0.127 | 1.385 | 0 | 20 |
| × Chemicals | 685 | 0.901 | 3.213 | 0 | 20 |
| × Pharmaceuticals | 685 | 0.137 | 1.263 | 0 | 19 |
| × Petroleum | 685 | 0.050 | 0.799 | 0 | 17 |
| × Rubber | 685 | 0.178 | 1.702 | 0 | 20 |
| × Glass | 685 | 0.155 | 1.419 | 0 | 20 |
| × Steel | 685 | 0.139 | 1.444 | 0 | 19 |
| × Nonferrous metals | 685 | 0.146 | 1.534 | 0 | 20 |
| × Metals | 685 | 0.070 | 0.996 | 0 | 19 |
| × General machinery | 685 | 0.578 | 2.757 | 0 | 20 |
| × Electrical appliances | 685 | 1.371 | 4.432 | 0 | 20 |
| × Transportation machinery | 685 | 0.634 | 3.056 | 0 | 20 |
| × Precision instruments | 685 | 0.145 | 1.353 | 0 | 17 |
| × Other manufacturing | 685 | 0.180 | 1.539 | 0 | 18 |
| $CO_2$_reduction_score | 685 | 5.743 | 1.113 | 1 | 10 |
| × Food | 685 | 0.524 | 1.651 | 0 | 7 |
| × Textiles | 685 | 0.172 | 0.978 | 0 | 8 |
| × Pulp and paper | 685 | 0.095 | 0.734 | 0 | 6 |
| × Chemicals | 685 | 1.057 | 2.329 | 0 | 10 |
| × Pharmaceuticals | 685 | 0.212 | 1.074 | 0 | 7 |
| × Petroleum | 685 | 0.042 | 0.498 | 0 | 7 |
| × Rubber | 685 | 0.134 | 1.006 | 0 | 10 |
| × Glass | 685 | 0.269 | 1.218 | 0 | 6 |
| × Steel | 685 | 0.321 | 1.379 | 0 | 10 |
| × Nonferrous metals | 685 | 0.174 | 0.987 | 0 | 7 |
| × Metals | 685 | 0.216 | 1.092 | 0 | 7 |
| × General machinery | 685 | 0.616 | 1.806 | 0 | 10 |
| × Electrical appliances | 685 | 0.851 | 2.059 | 0 | 10 |
| × Transportation machinery | 685 | 0.673 | 1.880 | 0 | 8 |
| × Precision instruments | 685 | 0.146 | 0.933 | 0 | 10 |
| × Other manufacturing | 685 | 0.241 | 1.167 | 0 | 9 |
| Food | 685 | 0.095 | 0.293 | 0 | 1 |
| Textiles | 685 | 0.031 | 0.173 | 0 | 1 |
| Pulp and paper | 685 | 0.018 | 0.131 | 0 | 1 |
| Chemicals | 685 | 0.178 | 0.383 | 0 | 1 |
| Pharmaceuticals | 685 | 0.039 | 0.195 | 0 | 1 |
| Petroleum | 685 | 0.007 | 0.085 | 0 | 1 |
| Rubber | 685 | 0.019 | 0.137 | 0 | 1 |
| Glass | 685 | 0.047 | 0.211 | 0 | 1 |
| Steel | 685 | 0.053 | 0.223 | 0 | 1 |
| Nonferrous metals | 685 | 0.031 | 0.173 | 0 | 1 |
| Metals | 685 | 0.039 | 0.195 | 0 | 1 |
| General machinery | 685 | 0.109 | 0.312 | 0 | 1 |
| Electrical appliances | 685 | 0.150 | 0.358 | 0 | 1 |
| Transportation machinery | 685 | 0.115 | 0.320 | 0 | 1 |
| Precision instruments | 685 | 0.025 | 0.156 | 0 | 1 |
| Other manufacturing | 685 | 0.044 | 0.205 | 0 | 1 |

Table 3 Estimation results

| | (1) | | | (2) | | |
|---|---|---|---|---|---|---|
| | IV | | | IV | | |
| | Coefficient | SE | | Coefficient | SE | |
| Ln_labor_cost | 0.119 | 0.026 | *** | 0.139 | 0.027 | *** |
| Ln_capital_cost | 0.429 | 0.025 | *** | 0.437 | 0.025 | *** |
| Ln_material_cost | -0.619 | 0.021 | *** | -0.635 | 0.022 | *** |
| $CO_2$_management_score | 0.022 | 0.003 | *** | - | - | |
| × Food | - | - | | 0.029 | 0.010 | *** |
| × Textiles | - | - | | 0.014 | 0.017 | |
| × Pulp and paper | - | - | | -0.022 | 0.016 | |
| × Chemicals | - | - | | 0.027 | 0.006 | *** |
| × Pharmaceuticals | - | - | | 0.053 | 0.014 | *** |
| × Petroleum | - | - | | 0.040 | 0.030 | |
| × Rubber | - | - | | 0.007 | 0.022 | |
| × Glass | - | - | | 0.010 | 0.012 | |
| × Steel | - | - | | 0.000 | 0.011 | |
| × Nonferrous metals | - | - | | 0.030 | 0.011 | *** |
| × Metals | - | - | | 0.023 | 0.016 | |
| × General machinery | - | - | | 0.010 | 0.007 | |
| × Electrical appliances | - | - | | 0.029 | 0.005 | *** |
| × Transportation machinery | - | - | | 0.010 | 0.006 | |
| × Precision instruments | - | - | | 0.036 | 0.014 | ** |
| × Other manufacturing | - | - | | 0.031 | 0.011 | *** |
| $CO_2$_reduction_score | 0.012 | 0.014 | | - | - | |
| × Food | - | - | | 0.069 | 0.045 | |
| × Textiles | - | - | | -0.174 | 0.114 | |
| × Pulp and paper | - | - | | 0.051 | 0.084 | |
| × Chemicals | - | - | | 0.011 | 0.029 | |
| × Pharmaceuticals | - | - | | -0.043 | 0.060 | |
| × Petroleum | - | - | | -0.647 | 0.254 | ** |
| × Rubber | - | - | | 0.010 | 0.089 | |
| × Glass | - | - | | 0.187 | 0.154 | |
| × Steel | - | - | | 0.013 | 0.072 | |
| × Nonferrous metals | - | - | | -0.218 | 0.107 | ** |
| × Metals | - | - | | 0.080 | 0.063 | |
| × General machinery | - | - | | 0.054 | 0.036 | |
| × Electrical appliances | - | - | | 0.011 | 0.039 | |
| × Transportation machinery | - | - | | 0.004 | 0.061 | |
| × Precision instruments | - | - | | -0.026 | 0.081 | |
| × Other manufacturing | - | - | | 0.068 | 0.047 | |
| Constant | 1.999 | 0.164 | *** | 1.850 | 0.256 | *** |
| Number of observations | 685 | | | 685 | | |
| Centered $R^2$ (second stage) | 0.679 | | | 0.704 | | |
| Endogeneity test (p-value) | 0.000 | | | 0.000 | | |
| Under-identification test (p-value) | 0.000 | | | 0.000 | | |
| Weak-identification test (F-value) | 4947.564 | | | 4314.754 | | |
| Over-identification test (p-value) | 0.236 | | | 0.184 | | |

Note 1: *, **, and *** indicate that the coefficient is significantly different from zero at the 10%, 5%, and 1% level, respectively.

Note 2: The Stock–Yogo weak ID test critical values at 5% maximal IV relative bias are 13.91 in Models (1) and (2).