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Abstract

This study investigates the effectiveness of the Kyoto Protocol on environmental performance and economic improvement using country-level panel data of 209 countries for the periods 1997–2008 and 2005–2008. We combine the propensity score matching and difference-in-difference methods to examine two hypotheses. The first hypothesis tests the environmental effectiveness that perceives the effect of the protocol in terms of reducing CO_2 emission. This hypothesis is accepted, suggesting effective CO_2 emission reduction among Annex 1 Parties. In contrast, the second hypothesis that assumes the positive international environmental agreement effect on economic performance is rejected, indicating that participating in Annex 1 has a negative effect on the economic growth. However, from the prediction about the environmental and economic effectiveness based on the result of the statistical analysis, CO_2 emissions reduction induced by the Kyoto Protocol exceeds the negative effect on the GDP.

Keywords: Difference-in-difference; Impact evaluation; International environmental agreements; Kyoto Protocol; Propensity score matching

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1 Introduction

Owing to the intensified environmental degradation, particularly in transboundary environmental problems, the need for establishing realistic and effective international instruments has arisen. Consequently, international environmental agreements (IEAs) have been established as mechanisms for transnational cooperation to cope with global environmental degradation and to deal with environmental problems across nations. By participating in IEAs to achieve the common goal of protecting the environment, each country can go a step towards improving their environmental performance (Caldwell 1990). Along with the proliferation of IEAs, studies that evaluate the effectiveness of IEAs have increased. However, due to the endemic nature of international policy, the effectiveness of IEAs is being questioned.

The Kyoto Protocol is one of the most influential IEAs with respect to the reduction of greenhouse gas (GHG) emissions, as it takes account of national differences in initial emissions, wealth, and capacity for change under the main principle of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) (Grubb 2004). To estimate its effectiveness, scholars have performed quantitative analysis using various methodologies and data, but the results obtained are still controversial. While proponents argue that the protocol has a significant effect on reducing emissions (Grunewald and Martínez-Zarzoso 2011; UNFCCC 2012), opponents claim that it is rather an empty promise and its implementation incurs huge expenses (Böhringer 2003; Böhringer et al. 2001; Huang et al. 2008; Kumazawa and Callaghan 2012; Nordhaus and Boyer 1999).

Furthermore, previous studies have mostly analyzed the environmental effectiveness aspect that studies the effect of an IEA in terms of how it eliminates or reduces environmental problems. Therefore, studies that consider the economic consequences on the participants along with the environmental effectiveness are lacking. Nevertheless, the Kyoto Protocol has tried to decrease the negative effect on economic performance with market-based mechanisms; it is supposed that IEAs improve not only environmental, but also economic performance (Golub et al. 2006; Manne and Richels 1998).

Based on this assumption, we posit two hypotheses on environmental performance and economic improvement. The first hypothesis investigates the protocol's effect on carbon dioxide (CO_2) emission reduction[1] and assumes that participating in Annex 1 of the Kyoto Protocol contributes to a reduction of CO_2 emissions. The second hypothesis predicts that there will be no adverse effects on the economic performance of parties in Annex 1.

To test these hypotheses, we combine the propensity score matching (PSM) and difference-in-difference (DID) methods to analyze the environmental and economic effectiveness of the Kyoto Protocol from the time of its adoption and entry into force to its target year. This technique allows us to compare the environmental and economic performance of the non-Annex 1 countries to those of Annex 1 countries while controlling for unobserved internal and external effect. We expect to gain deeper and precise understanding of the effectiveness of IEAs through the application of impact evaluation method to the IEA study.

The findings of this study differ somewhat from expectations. While the results provide robust empirical support for the first hypothesis, they do not support the second

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[1] Kim, Tanaka, & Matsuoka (2012) indicate that a well-designed IEA can improve environmental performance.

hypothesis. In other words, the Kyoto Protocol has a positive effect on CO_2 emissions reduction, but does not seem to help improve economic growth. Instead, participating in Annex 1 protocol has a negative effect on the gross domestic product (GDP).

The remainder of the paper is organized as follows: The following section provides a theoretical framework on the effectiveness of the Kyoto Protocol and establishes hypotheses about its environmental and economic aspects. Section 3 describes the data and specifies the methods employed in this study. The empirical results of the environmental and economic effectiveness of the Kyoto Protocol and the predictions based on regression results are presented in Section 4, and the final section concludes.

2 The Kyoto Protocol: Effectiveness Issues and Hypotheses

Here, we draw on brief information of the Kyoto Protocol and discussions about the effectiveness of IEAs. Then, we develop the hypotheses about its effectiveness and focus on the Kyoto Protocol based on the previous literature.

The Kyoto Protocol is an international agreement affiliated with the UNFCCC that was adopted in December 1997 in Kyoto, and came into force in February 2005. There are 192 Parties[2] to the Kyoto Protocol. This protocol admits that developed countries are mainly responsible for the high levels of GHG emissions so far. Therefore, internationally binding emission reduction targets were set that imposed a heavier burden on Annex 1 Parties[3] under the principle of "common but differentiated

[2] These include 191 States and European Union (EU).

[3] Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, European Union, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, Netherlands, New Zealand, Norway,

responsibilities." What is unique about this protocol is that three market-based mechanisms have been offered to meet their emission reduction target. These flexible mechanisms assist Annex 1 countries to meet their reduction obligations in a cost-effective way (de Chazournes 1998).

Based on the theoretical discussions of the IEAs' effectiveness in a framework of the Porter Hypothesis that provides a clue of theoretical potential that the environmental effectiveness of IEAs can be connected to the economic effectiveness, the two-dimensional effectiveness of the Kyoto Protocol can be formulated by reviewing previous studies. Therefore, the empirical models also focus on two hypotheses: The first aspect of effectiveness is the environmental effectiveness, which is estimated by the changes of environmental performance. In the case of the Kyoto Protocol, the level of CO_2 emission reduction is the key standard of judgment because of the data availability and its significant impact on global warming.

Indeed, some results of empirical testing have raised questions about the actual effectiveness of the Kyoto Protocol. Böhringer (2003) questioned the effectiveness of the Kyoto Protocol, believing it to be merely a symbolic policy. They assessed the potential performance of the protocol and insisted that there is no distinct emission reduction in the initial commitment period. However, they concluded that, although there is no effective emission reduction in the first commitment period, the ratification of the Kyoto Protocol is crucial for the continuation of the policy process of climate protection.

Some studies that have showed the lack of effectiveness of political agreements

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Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America (UNFCCC, n.d.).

in reducing emissions argue that the underlying main driving factors of CO_2 emission are industrialization. Kumazawa and Callaghan (2012) demonstrated that different emission reduction patterns are shown in the industrialized countries that are duty-bound to reduce CO_2 emissions. Huang et al. (2008) similarly argued that 38 industrialized countries are unable to meet their targets under the Kyoto Protocol within the specified time period.

On the other hand, arguments on the positive environmental effect of the Kyoto Protocol have indicated the decrease in CO_2 emissions. Considering the Kyoto Protocol and the Clean Development Mechanism (CDM), Grunewald and Martínez-Zarzoso (2011) analyzed the driving factors of CO_2 emissions with a dynamic panel data model for the period 1960 to 2009. They revealed that the obligations of the Kyoto Protocol have had a reducing effect on CO_2 emissions. UNFCCC (2012), which has investigated the national GHG emissions from 1990 to 2010, representatively examined the total aggregate GHG emissions among Annex 1 countries and found that 8.9 percent of total GHG emissions reductions are observed. However, it is difficult to distinguish the effect of the Kyoto Protocol since this report focuses on estimating simple changes of reduction over 1990–2010.

In brief, the results from the previous studies on the environmental effectiveness of the Kyoto Protocol are open to dispute. One of the major limitations of the existing literature is that they fail to distinguish how the IEA effect controls the characteristics of each nation. In this regard, some scholars have indicated the intrinsic difficulties of predicting impacts, such as dealing with hypothetical situations or controlling external factors (Aakvik and Tjøtta 2011; Frantzi 2008; Underdal 1992; Vollenweider 2013). For example, socio-economic status and the base level of pollutants differ from country to country; therefore, they have to consider in the quantitative analysis. Additionally, the IEA effect on the emission reduction has already been analyzed in a previous study applying EKC theory, which is focused on the global trend of emission reduction, but not specifically on those countries participating in Annex 1.

Therefore, there is a strong need to investigate more clearly the practical effect of the protocol on the CO_2 emissions with proper models that can distinguish the effect of the agreements. As is shown by the results of Aakvik and Tjøtta (2011), Kim et al. (2012), and Vollenweider (2013), quantitative analysis can capture the precise effect of emission reductions. This motivates us to test the first hypothesis whether the Kyoto Protocol improves the environmental performance or not.

Hypothesis 1: *Participating in Annex 1 of the Kyoto Protocol has a positive effect on the CO_2 emission reduction.*

Only a few studies have analyzed the effect of the Kyoto Protocol on national economic performance, or on other IEAs. As for the concerns over the cost of policy implementation, the existing empirical studies are skeptical about the economic effectiveness of the Kyoto Protocol. Nordhaus and Boyer (1999) conducted an economic analysis of the Kyoto Protocol and claimed that the emissions policy is highly cost inefficient, as the net global cost of the protocol reached approximately $716 billion in their analysis. Böhringer et al. (2001) also stated that the spillover effects of carbon abatement in industrialized countries on developing countries are significant. Hence, despite the lack of developing country's reduction obligations, serious problems of fair burden sharing occur.

However, as a representative of the stringent but flexible international environmental policies inherent in market-based mechanisms, the Kyoto Protocol encourages decreasing the negative effects on economic growth. In other words, the Kyoto Protocol encourages the application of the Porter Hypothesis, which suggests that a well-designed environmental policy can improve both environmental and economic performance by enhancing innovation (Lanoie et al. 2011; Porter and van der Linde 1995).

There are some evidences from empirical studies. For instance, according to Golub et al. (2006), costs can decline significantly through market mechanisms, such as international permit trading. Huang et al. (2008) also mentioned that the position of the UNFCCC Secretariat is to decouple economic growth and GHG emissions. Moreover, we also find some evidence from other empirical literatures. For example, Manne and Richels (1998) showed the possibility of the validity of the Porter Hypothesis in the Kyoto Protocol. They performed two scenarios regarding CO_2 emission cost and observed that GDP losses in 2010 differed from those predicted by their scenarios. Their results indicated that the prospects for technical progress are incorporated, and, therefore, the costs of a carbon constraint will be minimal. Concerning the relationship between emission trend and growth rate, Lindmark (2002), in a case study of Swedish CO_2 emissions, argued that sustained growth rates were associated with less technological and structural changes relating to CO_2 emissions. Thus, it was suggested that time-specific technological clusters might affect Environmental Kuznets Curves (EKC) patterns.

Based on these studies, we conduct empirical testing to verify the economic effectiveness of the Kyoto Protocol. Drawing on the assumption that the Kyoto Protocol improves environmental performance in line with economic performance, we posit a second hypothesis, which is the main hypothesis of the study.

> **Hypothesis 2:** *The effect of the Kyoto Protocol on the economic performance of Annex 1 Parties will not be negative.*

3 Empirical model

3.1 PSM and DID methods

We adopt an impact evaluation technique that combines the PSM and DID methods for estimating the environmental and economic effectiveness of the Kyoto Protocol. These methods are widely used in the fields of ODA, economics, and politics for evaluating program effectiveness (Cadot et al. 2012; Michalek 2012; Mu and Van de Walle 2007). However, there are not many previous studies on IEAs (Aakvik and Tjøtta 2011; Kim et al. 2012; Vollenweider 2013). This impact evaluation technique has its own advantage because it can create a synergy effect.

By combining these methods, we can control not only the selection bias, but also the problem of unobserved heterogeneity. The PSM method constructs a statistical comparison group from a model on the probability of participating in the program on observed characteristics; and then, object variables of participants and non-participants with similar propensity scores are compared to evaluate the program effect. The DID method assumes that unobserved heterogeneity in participation is time invariant, so the bias can be eliminated by the differencing process. Moreover, it is possible to set counterfactuals quantitatively by means of the DID estimator. Comparing actual and counterfactual outcomes is very crucial, but tricky task since the same sample with and without a program cannot be observed at the same time (Khandker, Koolwal, and Samad 2010). The DID method compares the observed changes in the outcomes for a sample of participants and non-participants between adoption and target year. Therefore, the outcome changes for non-participants represent the counterfactual outcome changes.

First of all, to estimate the propensity score, we assume that X is the observed characteristics of research objects: $\hat{P}(X|T = 1) = \hat{P}(X)$. The variables in this study include GDP, population, and the status of CO_2, which are considered proper variables for calculating a propensity score that reflects representative socio-economic conditions and the status of the environment of each country, as determinants for the characteristics of participants and non-participants. Since this study is focused on a single protocol, which is aimed at reducing CO_2 emission, the status of CO_2 emission is used for both environmental and economic models.

The DID matching estimator is also used in the analysis since it is expected to better match the participants and non-participants of the Kyoto Protocol with the data, which has participants and control observations for both before and after the program (Khandker et al. 2010). Based on the propensity score, the region of common support and balancing tests are conducted through PSM estimation, $\hat{P}(X|T = 1) = \hat{P}(X|T = 0)$. The balancing property is satisfied and observations that fail to be included in the common support are deleted in the matching process. Consequently, only selected matched Annex 1 countries and control countries based on the propensity score of the baseline year are used for the DID.

In this study, the DID matching approach is implemented in two time periods: the adoption year and the target year of the Kyoto Protocol. The DID matching estimator can be adopted to take advantage of the obtained panel data since it can be conducted to better match control and treated observations on pre-program feature, *X*, if there are participants and control observations in both before and after program data (Khandker et al. 2010).

The DID method is usually estimated in a regression framework (Khandker et al. 2010). We conduct the fixed-effect estimation model based on a Wu-Hausman test to analyze the effectiveness of the Kyoto Protocol throughout this analysis. With the fixed-effect estimation model, the unobserved effect prior to estimation is removed, and so time-constant explanatory variables can be controlled (Wooldridge 2009).

Consequently, it is possible to control time-varying covariates and unobserved time-invariant individual heterogeneity. By differencing both the right- and left-hand sides of the equation, the program effect is calculated from the coefficient of ΔT_{it} (i.e., $\emptyset$), which is defined as being affiliated to Annex 1 countries, and has a value of 1 if a country *i* has joined the Kyoto Protocol in year *t* and 0 otherwise. Thus, we have the following equation:

$$(Y_{it} - Y_{it-1}) = \emptyset(T_{it} - T_{it-1}) + \delta(X_{it} - X_{it-1}) + (\eta_i - \eta_i) + (\varepsilon_{it} - \varepsilon_{it-1})$$
$$\Rightarrow \Delta Y_{it} = \emptyset \Delta T_{it} + \delta \Delta X_{it} + \Delta \varepsilon_{it}$$

Where Y_{it} denotes the environmental or economic performance of participating country i on the year of t, T_{it} is whether the country participates in IEAs or not, and other control variables are included in the variable X_{it}. ε_{it} indicates other unobserved characteristics and unobserved time-invariant individual heterogeneity η_i is eliminated in fixed-effect model.

3.2 Two-time-period setting

The two-time-period setting for the base year and the target year of the Kyoto Protocol is a crucial part of the impact evaluation, combining the PSM and DID methods. To consider both with-and-without comparison and before-and-after comparison, this advanced technique requires experimental and comparison groups and two time-period data to assume reliable counterfactual situations.

For the base year, we consider an adoption year, an effectuation year, and a ratification year because the base year is usually set as the time that nations participate in IEA (Aakvik and Tjøtta 2011). The history of the Kyoto Protocol is not relatively long compared to other IEAs. Indeed, the Kyoto Protocol was adopted in 1997 and it came into force in 2005. Hence, for our empirical analysis, we use not only the adoption year, but also the year it came into force. Moreover, we focus on the gap between the date of adoption and date the Kyoto Protocol came into force. To find out the effectiveness of the protocol in more detail, we use in the model the date it came into force as the base year in company and the year it was adopted.

As for the target year, many previous studies have proposed that the goal year for reduction of pollutant emission is suitable for the target year of each IEA (Aakvik and Tjøtta 2011; Helm and Sprinz 2000). Therefore, it is reasonable to adopt the goal year for the IEA as the target year, if the IEA states a specific time period. In fact, the first official commitment of the Kyoto Protocol started in 2008 and ended in 2012, and the second commitment period has been set from January 1, 2013 to December 31, 2020 in the Doha Amendment in 2012. However, we focus on the regime participation itself and investigate the effect on the environment and economy of signatory countries before and after the protocol. Many previous studies have also estimated the effectiveness of the Kyoto Protocol on emission reduction with the data before the commitment period. In addition, quantitative data for the empirical analysis is limited for the recent years. Hence, this study sets the target year, 2008, as the goal year of the Annex 1 countries. This is applied as the target year because of it being the first impact evaluation of the Kyoto Protocol. Note that the analysis of the effectiveness of the Kyoto Protocol after 2008 will be conducted in further research by securing sufficient data.

3.3 Models for Testing Hypotheses

This study aims to shed light on the effectiveness of the Kyoto Protocol on environment and economy by considering pollutant reduction and economic growth trends of both participants and non-participants. Therefore, we propose two models to observe the effects of the Kyoto Protocol on member countries. Both environmental and economic models contain the program effect variable—an "IEA dummy"—for verifying the effectiveness of the protocol. Moreover, an Organization for Economic Cooperation and Development (OECD) dummy variable is appended to both equations to verify the Kyoto Protocol's impact on the environmental performance of OECD members.

The environmental effectiveness model includes a GDP variable that reflects the relationship between CO_2 emissions and GDP. The model includes the logarithmic variables of CO_2 emissions and GDP variables. In addition, both dummy variables of IEA effect and OECD countries are appended for investigating the IEA effect and whether there are any differences in their effects on emission reduction among OECD countries. The environmental effectiveness model is given by the following equation:

$$Ln(\text{CO}_2\ \text{Emissions}) = \alpha_0 + \alpha_1 \text{IEA dumm}y + \alpha_2 Ln(\text{GDP}) + \alpha_3 \text{OECD dummy} + \alpha_4 \text{Time dummy}$$

Next, the economic effectiveness model of the Kyoto Protocol is based on the Cobb-Douglas GDP function. Therefore, this model includes capital, labor, and human capital variables, as components of the GDP function. All the variables are in logarithmic terms, except the dummy variables. The model encompasses the IEA and OECD dummy variables within the environmental effectiveness model. Thus, we use the following equation to test the economic effectiveness hypothesis that posits no negative effect on the economic growth of Annex 1 countries:

$$Ln(\text{GDP}) = \beta_0 + \beta_1 \text{IEA dummy} + \beta_2 Ln(\text{Capital}) + \beta_3 Ln(\text{Labor}) + \beta_4 Ln(\text{Human Capial}) + \beta_5 \text{OECD dummy} + \beta_6 \text{Time dummy}$$

When estimating the effectiveness of the protocol, potential statistical problems appear: Traditional regression models, such as the one shown above, assume that all independent variables are exogenous, that is, explanatory variables that are uncorrelated with the error term (Wooldridge 2009). However, many variables, particularly economic data, face the problem of endogeneity in multiple regression models. To overcome this statistical obstacle, the instrumental variable (IV) method is one of the options.

This analysis considers the above problem to draw precise results. The two models on the environmental and economic effectiveness of the Kyoto Protocol can be described by simultaneous equations. Therefore, the $Ln(\text{GDP})$ of the environmental effectiveness model has to solve the endogenous problem. The estimation of the environmental equation, which is included in the variables of $Ln(\text{GDP})$, has to be calculated while taking the endogenous variables problem into account. The endogeneity of the GDP variables can be verified with the Hausman test. Therefore, this analysis applies a Two-Stage Least Squares (2SLS) approach by applying the IV method for estimating the environmental effectiveness model.

The basic process of 2SLS estimator is consists of three steps: First, because the dependent variable $Ln(\text{GDP})$ of the economic equation model is an endogenous explanatory variable of the environmental effectiveness model, the within estimator is calculated from IV, such as $Ln(\text{Capital})$, $Ln(\text{Labor})$, and $Ln(\text{Human Capial})$, and exogenous explanatory variables. Second, a fitted value of $Ln(\text{GDP})$ is estimated from the estimator calculated by the previous step; $\widehat{Ln(\text{GDP})}$ presents the fitted value of $Ln(\text{GDP})$. Third, the adjusted regression model containing $\widehat{Ln(\text{GDP})}$ instead of the endogenous explanatory variable $Ln(\text{GDP})$ is established for investigating the within estimator of the environmental effectiveness of the Kyoto Protocol. Accordingly, we estimate the following equation of environmental effectiveness to gain the fitted value of the 2SLS fixed-effect estimator:

$$Ln(\text{CO}_2\ \text{Emission}) = \gamma_0 + \gamma_1 \text{IEA dumm}y + \gamma_2\, \widehat{Ln(\text{GDP})} + \gamma_3 \text{OECD dummy} \\ + \gamma_4 \text{Time dummy}$$

The empirical models for testing hypotheses are estimated using STATA/SE 11.2 for windows (32-bit).

4 Data description

To examine the environmental and economic effectiveness of the Kyoto Protocol, we use a country-level panel dataset of 209 countries for the period 1997–2008. Through the process of PSM, we use only the matched samples of base year and target year in the regression analysis. Therefore, some countries, which are succeeding in the matching process of, are used in the final estimations.

The empirical models contain two binary indicators: First, the program effect variables of the models determine whether the parties belong to Annex 1 or not. This indicator is given a value of 1 if the country is included Annex 1. The information regarding the Kyoto Protocol participation by each country in the base year and target year is adopted from UNFCCC (n.d.), which is the secretariat of the Kyoto Protocol. Second, the OECD dummy is another variable that is given a value of 1 if a nation is a member of the OECD countries[4]. Third, the time dummy is given a value of 1 if the sample is in the target year.

As shown in Table 1, all the remaining variables are collected from the World Development Indicators (WDI) (World Bank n.d.). To estimate the environmental effectiveness equation, the country-level emission data of CO_2 and GDP of each country is collected. Even though CO_2 emissions (kt) are available from various sources, only the most reliable WDI data is used.

We use the dataset that contain as many countries as possible for the GDP function

[4] Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israël, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States (Organisation for Economic Co-operation and Development (OECD, n.d.).

of the economic effectiveness equation. Consequently, gross fixed capital formation, total labor force participation rate (parentage of total population ages from 15 to 64), and adjusted savings-education expenditure (current US dollars) are used as capital, labor, and human capital variables, respectively. Owing to the data limitation, GDP and gross fixed capital formation are in constant US dollars from the year 2000, while adjusted savings-education expenditure is in current US dollars.

Table 2 shows the descriptive statistics of variables for both 1997 and 2005 base year models after the matching process.

5 Results

Table 3 reports the results of the fixed-effect regressions combining PSM with DID methods that reflects the environmental and economic effectiveness of the Kyoto Protocol. Since only the matched samples are included in the regression models, we use 171 or 169 samples (about two-time pairs of 84 or 86 nations) for our analysis. The effect of the Kyoto Protocol on the environment and economy of Annex 1 Parties is presented with the coefficients of the IEA variables.

Note that we drop the OECD dummy variables in the base year 2005 regressions of both the environmental and economic effectiveness analyses since all parties belonging to Annex 1 have also been OECD members since 2005. In addition, we use all variables (excluding dummy variables) as natural log values.

5.1 Environmental effectiveness

The first and second columns of Table 4.3 report the results of the environmental effectiveness of the Kyoto Protocol. Overall, the first model fits the data reasonably well. Although R^2 of the 2005 base year model is almost at the same level, the coefficient of GDP is also statistically significant in the 1997 base year model. R^2 is 0.825 for the 1997 base year model and 0.807 for the 2005 base year model, which indicate that more than 80% of the variations in CO_2 emission can be explained by both models.

First, the IEA dummy variables indicate the effectiveness of the Kyoto Protocol on emission reduction. The coefficients of the IEA dummy are statistically significant at 1% level with a negative sign in both the columns. These results show that belonging to the group of Annex 1 countries has a significant effect on the reduction of CO_2 emissions. Specifically, Annex 1 countries are approximately 25% more effective in reducing CO_2 emissions than non-participating countries in the 1997 base year model, and approximately 10% more effective in the 2005 base year model. These highly significant results suggest the evidence to support Hypothesis 1, which assumes that participating in Annex 1 of the Kyoto Protocol has a positive effect on reducing CO_2 emissions.

The above results are consistent with the discussions concerning the real influence of the Kyoto Protocol (Martínez-Zarzoso 2011; UNFCCC 2012). Moreover, these results support the previous studies about other pollutants that argue that there is a positive effect of participating in IEAs for pollution reduction (Helm and Sprinz 2000; Kim et al. 2012; Murdoch et al. 1997). They realize that engaging in international environmental governance is an effective way to prevent the discharge of pollution. Since this study utilizes advanced methods, which can control both pre- and post-program group differences, the effectiveness of the Kyoto Protocol has become clearer, and therefore, it complements the limitations of the previous studies.

Second, the signs of the coefficients of the GDP variables, which are used as IV for the economic effectiveness model for solving the problem of endogenous variables, are positive in both the models. From this result, it is revealed that CO_2 emission increase with economic development. However, only the GDP variable of the analysis of the base year 1997 is statistically significant at the 10% level, whereas it seems hard to derive a statistically significant result from the linear relationship between economic growth and CO_2 emissions in the second model. Although the research period of the second model covers only four years, this contradicts the early findings by Kumazawa and Callaghan (2012) and Huang et al. (2008) that the levels of CO_2 emissions are highly affected by the level of economic activity. Such insignificance may be due to the stage of economic growth of some of the developing countries, which implies that they are still experiencing the negative influences of economic development during the period of the second model, thus exceeding the impact of the IEAs.

This result supports the argument that CO_2 emissions and economic growth have a positive relationship. From the empirical result of the first model, it implies that a 1% increase in GDP triggers more CO_2 emissions by about 36%. Some previous studies have tried to determine whether EKC is an adoptable universal theory in CO_2 emissions, and explain that CO_2 emissions tend to increase in line with the economic development because CO_2 emissions are closely related to fossil fuel usage and industrial development. de Bruyn, van den Bergh, and Opschoor (1998) investigated the relationship and economic growth with CO_2, Nitrogen Oxide (NO_X), and Sulphur Dioxide (SO_2) emissions, and argued that emissions correlate positively with economic growth, but the structural and technological changes might help reduce emissions. Talukdar and Meisner (2001) also found the evidence supporting the monotonic relationship between CO_2 emissions and economic growth that decreasing beyond a particular turning point is not identified in their analysis. To sum up, empirical evidences from other studies support a monotonic relationship between GDP and CO_2 emission, even though the existence of an EKC for CO_2 is still disputed (Lantz and Feng 2006).

Finally, the OECD and time dummies have an insignificant impact on CO_2 emissions in both base year models. That is, there are no statistically significant differences in CO_2 emission reduction among OECD countries from before to after the Kyoto Protocol.

5.2 Economic effectiveness

The third and last columns of Table 3 provide the results on the economic effectiveness of the Kyoto Protocol. First, the IEA dummy is highly significant at more than 5% significance level with negative signs. This result demonstrates that being one of the Annex 1 countries has a negative effect on economic performance. The economic performance of Annex 1 countries deteriorates by approximately 10% from 1997 to 2008 and 3% from 2005 to 2008. From this result, we find that Annex 1 counties, on which reduction obligations are imposed, show lower economic growth than other counties. Consequently, Hypothesis 2 that assumes no negative economic effects from an IEA is rejected.

These findings coincide with the outcomes of the empirical analyses by Nordhaus and Boyer (1999). Although most Annex 1 countries are developed countries and the analysis period is prior to the beginning of the first official commitment period, curtailment of economic growth may appear due to expected socio-economic costs, investments, and corresponding policies for emission reduction that can be a burden to the Annex 1 countries. As a result, the economic burden is placed completely on Annex 1 countries, and their economic outputs are reduced due to the need for energy reduction, which increases production costs (Nordhaus and Boyer 1999).

This study assumes that participating in Annex 1 does not offset economic performance, since the applicability of the Porter Hypothesis built on the flexible market-based mechanisms is highly acclaimed. However, the empirical result of the economic effectiveness of the Kyoto Protocol shows that Annex 1 countries cannot avoid the economic burden of compliance costs in the analysis period. Contrary to our expectations, the result of the Porter Hypothesis does not seem to be a valid model for determining the economic effectiveness of the Kyoto Protocol.

Two pieces of theoretical evidence can be considered the reasons for this result. First, the institutional factors, including the enforcement, sanction, or implementation procedures of the Kyoto Protocol influence the effectiveness of the protocol. For example, the legalization and flexibility mechanisms of IEA can either worsen or improve its effectiveness (Böhmelt and Pilster 2010). More specifically, legal binding force may have a beneficial effect on the effectiveness whereas flexible mechanisms provide the capacity to rapidly adjust to new circumstances in the implementation process (Böhmelt and Pilster 2010; Hafner-Burton and Tsutsui 2005; Kucik and Reinhardt 2008).

Second, the CDM mechanism, which is prescribed in Article 12 of the protocol, can be another reason. With CDM mechanism, Annex 1 Parties are allowed to meet part of their emission reduction commitments under the Kyoto Protocol by buying Certified Emission Reductions (CER) of CDM emission reduction projects in developing countries (Carbon Trust 2009). If Annex 1 Parties participate in CDM projects to implement project-based emission reductions in developing countries, their need for research and development of technology or systems for emission reductions shrinks since comparatively lower technology is still efficacious in lowering countries' emissions. Therefore, with the CDM mechanism, it is difficult to present evidence to support the Porter Hypothesis that supposes that well-made environmental regulations encourage innovation and eventually achieve cost savings. Thus, the effort of Annex 1 Parties to reduce emissions in developing countries is hard to induce cost cutting in one's own country.

Note that the analysis period may not be satisfactory to examine the economic effectiveness of the Kyoto Protocol, since the practical effects of international environmental policies take a long time to manifest. More long-term follow-up studies are needed to show that international environmental policies have positive effects for both environmental and economic performance.

Moreover, the control variables of the elements of production functions indicate that while the coefficients of capital and human capital variables show positive signs and are statistically robust, labor variables are negative and the estimated coefficients are not statistically robust. Capital variables are statistically significant at 1% level, and about 29% of GDP growth is observed per 1% of capital increase in the 1997 base year model. The 2005 base year model shows a 14% improvement in GDP per 1% of capital growth. Furthermore, the human capital variable is also statistically significant and has an approximately 8% and 13% positive effect on GDP in each model. In contrast, labor has no statistically significant effect on the economic growth in this analysis. These results indicate that capital investment and human capital act as national economic locomotives.

Finally, according to the first model, the OECD dummy variable has a highly significant effect on GDP. The economic performance of OECD member nations is approximately 20% higher than that of other countries. This suggests that the economic level of OECD countries is relatively better than other countries. The coefficients of the time dummy variable show positive signs in both models, much like the analysis of the environmental effectiveness, but highly significant at 1% level. Hence, we can infer that the introduction of the Kyoto Protocol has had a significant impact upon economic performance.

5.3 Prediction of the effectiveness among Annex 1 Parties

The step that follows the fixed-effect regression procedure with the impact evaluation combining PSM and DID methods is the estimation of the environmental and economic effectiveness of the Kyoto protocol, based on the result of both the base year models. This prediction value is calculated among Annex 1 countries. Table 4 reports the predicted estimations of the real and hypothetical IEA effect on the CO_2 emissions and GDP growth for both the base years.

In this prediction, the real and hypothetic values are compared to examine the expected differences. The real situation of CO_2 emissions and GDP are regarded as the estimated values when nations participate in Annex 1. Therefore, this estimated value of 2008 is calculated based on the real data of the base year, applying the IEA dummy variable 1. On the contrary, the hypothetical situation is an assumption if nations had not participated in Annex 1. Thus, the IEA dummy variable is shifted to 0 for presuming a counterfactual situation, and then the hypothetical value is estimated as above.

In the case of environmental effectiveness, participating in Annex 1 produced a positive effect on the CO_2 emission. The gap between the real and hypothetical estimation is 2,452 MT in the 1997 base year model and 1,308 MT in the 2005 base year model. This implies that if countries were not required to reduce CO_2 emissions, Annex 1 countries would have emitted more CO_2—about 28% based on the first model and 10% for the second model.

On the contrary, in the case of economic effectiveness, as discussed in the result section, participating in Annex 1 has had a negative effect on GDP growth. More specifically, 2,793 billion US dollars—approximately 10% GDP growth—is observed in the hypothetical situation of the 2005 base year model, whereas 816 billion US dollars— 3% GDP growth—is estimated in the 2005 base year model. These large gaps indicate considerable economic impact on IEA participants.

Note that although this prediction is accomplished with the fixed-effect regression equations that are estimated precisely, it is inevitable that there will be some gaps between the actual measurement value of 2008 and the predicted value due to unexpected socio-economic changes. In particular, since the target year of this study is 2008, which was when the impact of the subprime mortgage crisis occurred, it is difficult to reflect a rapid decrease of GDP.

These numerical results contribute to our understanding of the actual amount of emissions reduction and economic burden caused by the Kyoto Protocol. Overall, the prediction results demonstrate that even though the effect of the Kyoto Protocol on Annex 1 countries offsets economic growth, its emission reduction effect is much greater than the hindrance effect to economic growth. However, regarding the possibility of reducing costs, the Kyoto Protocol has not managed to improve both in terms of environmental and economic performance.

6 Conclusion

Along with the increasing number of IEAs, analyzing the effectiveness of IEAs has recently become of interest to scholars. Despite this increasing academic interest, quantitative studies on the effectiveness of IEAs are still limited and often controversial. Research on the effectiveness of IEAs has largely focused on the environmental performance, and only few studies have tested the economic effectiveness of IEAs.

We attempted to examine the competing claims about the effectiveness of the Kyoto Protocol on environmental performance and economic improvement using country-level panel data of 209 countries for the period 1997–2008. We estimated the effectiveness combining the PSM and DID methods. To provide better understanding, we used two models by setting different base years.

We found that only the first hypothesis that assumed that the Kyoto Protocol had a significant effect on reducing emissions have a robust empirical support. The results confirmed effective CO_2 emission reductions among Annex 1 Parties for both base year models at a highly significant level. The second hypothesis that assumed that the IEA had no negative effect on GDP was rejected, implying that even though the Kyoto Protocol included the establishment of market-based mechanisms for reducing costs, it is currently difficult to improve both environmental and economic performance. Institutional factors of IEAs and the slippage effect through the CDM mechanism are suggested with theoretical evidence.

This study opens avenues for further research in analyzing other IEAs from a long-term perspective. Although the empirical results are robust and provide evidence about the effectiveness of IEAs, the research objective is limited to the Kyoto Protocol and the analysis periods are not sufficiently complete. Therefore, the possibility exists for generating a more interesting result if the analysis is conducted with longer periods, including the first commitment period. Future research could use broader data on various IEAs to estimate and provide a more generalized and detailed result on whether IEAs improve environmental performance in line with economic performance. Finally, the synergistic effect between environmental policies and economic performance can be evaluated in the field of IEAs.

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Table 1 Sources of Data

Variables	Sources
Status of participating in IEAs	UNFCCC (n.d.).
CO_2 emissions (kt)	WDI (World Bank n.d.)
Social Factors (GDP, Population)	
GDP Function (Capital, Labor, Human Capital)	

Table 2 Descriptive Statistics of Full Sample

Variables	*N*	Mean	Std. Dev.	Min	Max
1997 base year model					
IEA dummy	171	0.222	0.417	0	1
Ln(CO_2 Emissions)	171	10.778	1.980	5.905	15.761
Ln(Capital)	171	23.353	1.968	18.516	28.373
Ln(Labor)	171	4.201	0.138	3.766	4.450
Ln(Human capital)	171	21.961	2.026	17.183	27.260
Ln(GDP)	171	24.847	1.946	20.050	30.116
OECD dummy	171	0.345	0.477	0	1
Time dummy	171	0.444	0.498	0	1
2005 base year model					
IEA dummy	169	0.231	0.423	0	1
Ln(CO_2 Emissions)	169	10.923	1.915	5.982	15.761
Ln(Capital)	169	23.631	1.826	19.063	28.419
Ln(Labor)	169	4.215	0.137	3.752	4.483
Ln(Human capital)	169	22.305	1.912	17.687	27.260
Ln(GDP)	169	25.097	1.831	20.819	30.116
OECD dummy	169	0.355	0.480	0	1
Time dummy	169	0.462	0.500	0	1

Table 3 Empirical Results on the Effectiveness of the Kyoto Protocol

Model	Environmental effectiveness		Economic effectiveness	
Object variable	*Ln*(CO_2 Emissions)		*Ln*(GDP)	
Base year	1997	2005	1997	2005
Target year	2008	2008	2008	2008
IEA dummy	-0.246***	-0.097***	-0.097***	-0.029**
	(0.054)	(0.037)	(0.024)	(0.014)
Ln(Capital)	-	-	0.286***	0.137**
			(0.054)	(0.059)
Ln(Labor)	-	-	-0.298	-0.210
			(0.278)	(0.235)
Ln(Human capital)	-	-	0.079*	0.126***
			(0.046)	(0.032)
$Ln(\widehat{\text{GDP}})$	0.360*	0.195	-	-
	(0.205)	(0.374)		
OECD dummy	-0.192	-	0.201***	-
	(0.240)		(0.019)	
Time dummy	0.135	0.076	0.260***	0.075***
	(0.097)	(0.066)	(0.034)	(0.018)
Constants	1.882	6.013	17.512***	19.911***
	(5.043)	(9.384)	(1.569)	(1.291)
R^2	0.825	0.807	0.955	0.966
Number of sample	171	169	171	169
Number of groups	89	86	89	86

Note: ***, **, and * denote 1%, 5%, and 10% significance levels, respectively.

Table 4 Prediction of the Effectiveness of the Kyoto Protocol

	Model	Participate (real)	Non-participate (hypothetic)	(hypothetic)-(real) (%)
CO2	1997	8,790	11,242	2,452
(emissions (MT))				(27.890%)
	2005	12,844	14,153	1,308
				(10.186%)
GDP	1997	27,419	30,212	2,793
(constant 2000				(10.186%)
Billion US	2005	27,725	28,540	816
dollars)				(2.942%)

Note: The actual measurement value of CO_2 is 114,263MT in 2008 and 14,511MT in 2007. The actual measurement value of GDP is 23,064 billion US dollars in 2008 and 29,952 billion US dollars in 2007.