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23 April 2010

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Abstract

Our study empirically investigates the effects of the Kyoto Protocol's quantified emission limitation or reduction commitments on various greenhouse gas (GHG) emissions such as CO_2, CH_4, N_2O and other greenhouse gases, consisting of HFCs, PFCs and SF_6. These GHG emissions are considered to be the main source of global warming issues and 39 countries approved to meet the commitments by ratifying the Kyoto Protocol. Our empirical analysis is based on the STIRPAT model, the stochastic version of the IPAT model, using the data of 119 countries in 1990, 1995, 2000 and 2005. Our main findings are that the effects of the commitments to the Kyoto Protocol (1) are significantly negative for the cases of CO_2 and CH_4 emissions, (2) are not significant for the case of N_2O emissions and (3) are significantly positive for the case of other greenhouse gas emissions. These results have important policy implications for global warming issues.

Keywords: Greenhouse gas emissions; Kyoto Protocol; Sustainability; IPAT; Panel data
JEL Classification: O19; Q54; Q56

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1 Introduction

Global warming is an important issue for all people in the world. Once greenhouse gases (GHGs) are generated, they accumulate in the atmosphere for a very long period. For this reason, the scope of their impact is not only limited to the present generation, but will continue to affect generations to come. Due to these long lasting effects, global warming must be dealt with seriously in order to achieve environmental and economic sustainability. Global warming has a strong relationship with sustainability in terms of genuine saving (GS).[1] From its definition, a country's GS value increases if GHG emissions like CO_2 emissions decrease, leading to the improvement of its sustainability. Based on this assumption, analyzing the mechanism of GHG emissions would be useful for the study of sustainability.

In recent years a number of researches warn that an increase in the level of GHG emissions in the atmosphere will cause serious problems.[2] There is also a collective view among the majority of the science community suggesting that anthropogenic factors (called driving forces) play an important role in the GHGs increment.

International negotiations to prevent global warming started in the late 1980s. In 1988, the United Nation Environment Programme (UNEP) and the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC). The United Nation Framework Convention on Climate Change (UNFCCC) was adopted by the congress in 1992. The Kyoto Protocol was established at the third conference of the parties (COP3) in 1997. This protocol obliges approximately 40 developed countries (Annex 1 countries in the UNFCCC) to limit or reduce GHG emissions. The Kyoto Protocol covers six kinds of GHGs such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).[3] Non-CO_2 GHGs are also generated from human activities such as industry, agriculture and energy generation as pointed out by Khalil (1999). According to the IPCC, the fractions of GHGs from man-made sources are 76.7% for CO_2, 14.3% for CH_4, 7.9% for N_2O and 1.1% for other GHGs (HFCs, PFCs and SF_6) respectively (IPCC, 2007c, p.103). Atmospheric concentrations of long-living GHGs (CO_2, CH_4 and N_2O) have increased rapidly since the industrial era (IPCC, 2007a, p.135). Additionally, non-CO_2 GHGs have greater global warming potential (GWP) than CO_2, defined by the relative value of global warming effects of each GHG. For example, the GWPs of CH_4, N_2O and SF_6 are 25, 298 and 22800 respectively if the GWP of CO_2 is assumed to be unity in a time span of 100 years (IPCC, 2007a, pp.212-213).[4]

[1] The World Bank (2009) defines GS as "*adjusted net savings are equal to net national savings plus education expenditure and minus energy depletion, mineral depletion, net forest depletion, and carbon dioxide. This series excludes particulate emissions damage.*" GS is used by many studies as an indicator for judging a country's sustainability (e.g., Hamilton and Clemens 1999; Arrow et al. 2004; Sato et al. 2009).

[2] IPCC (2007b) points out that rises in sea level, poor agricultural harvests, and damage to human health may be caused by global warming.

[3] In this paper, the term "all GHGs" refers to these six kinds of GHGs.

[4] As for HFCs and PFCs, which include a lot of species, their GWPs are different from each other and are

Reilly et al. (1999) study the emissions of GHGs other than CO_2 and point out the possibility of cost effective measures to prevent global warming. They show that the cost of a multi-gas control strategy could be much cheaper than a CO_2-only strategy in fulfilling the Kyoto Protocol. Rao and Riahi (2006) and van Vuuren et al. (2006) also argue that the cost of GHG reduction would decrease by considering both CO_2 and non-CO_2 gases. The Kyoto Protocol is a precious milestone for preventing global warming, and to further mitigate global warming, it might be important to include all GHGs into the analysis. Therefore, analyzing the effects of the Kyoto Protocol provides important policy implications.[5] Although there are many studies on the Kyoto Protocol such as York (2005), Zahran et al. (2007) and Swinton and Sarkar (2008), few researches have examined the effects of the Kyoto Protocol by taking all of the GHGs into consideration. Grunewald and Martínez-Zarzoso (2009) analyze the Kyoto Protocol's reducing effect on CO_2 emissions by categorizing countries based on income level and find that the Kyoto Protocol has a significant effect in reducing CO_2 emissions in both developed and developing countries. Unlike Grunewald and Martínez-Zarzoso (2009), which focus only on CO_2 emissions, our study pays attention to all GHG emissions and compares each of the results.

Specifically, our study empirically investigates the effects of the Kyoto Protocol's quantified emission limitation or reduction commitments on various GHG emissions such as CO_2, CH_4, N_2O and other greenhouse gases (HFCs, PFCs and SF_6). Our empirical analysis is based on the STIRPAT model, the stochastic version of the IPAT model as mentioned in the next section. Our sample consists of 119 countries in 1990, 1995, 2000 and 2005. Additionally, we utilize the annual data of CO_2 emissions from 1990 to 2005 to check the robustness of our analysis. Our estimation results show that the Kyoto Protocol is effective in reducing CO_2 and CH_4 emissions, whereas its effect is unclear on N_2O emissions and significantly positive on other greenhouse gas emissions. These results have important policy implications for global warming issues. While previous studies on these problems tend to merely focus on CO_2 emissions, our results suggest that the emissions of GHGs other than CO_2 should be taken into account as well.

The structure of this paper is as follows. Section 2 explains the IPAT model and its stochastic version, the STIRPAT model, which are the methods for our analysis. Section 3 provides the empirical analysis, which includes the estimation methodology, data and estimation results. Section 4 is the conclusion.

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much higher than that of CO_2. Note that the Kyoto Protocol is based on the GWPs in the IPCC second assessment report. This report shows that the GWPs of CH_4, N_2O and SF_6 are 21, 310 and 23900 respectively if the GWP of CO_2 is assumed to be unity in a time span of 100 years.

[5] Although our study focuses on the effects of the Kyoto Protocol, den Elzen et al. (2005), van Steenberghe (2005) and den Elzen et al. (2007) study the post-Kyoto abatement costs based on different future commitments of countries.

2 Theoretical framework

To analyze the driving forces of GHG emissions generated from human activities, the IPAT model (or equation) developed by Ehrlich and Holdren (1971) is useful. This model is based on the concept that population growth would harm (or change) the environment. As widely recognized, the environmental Kuznets curve (EKC) hypothesis assumes the unity of the population elasticity. Unlike the notion of the EKC, the IPAT model utilizes the total population as an explanatory variable. This permits us to explicitly estimate the population elasticity of gas emissions.

The IPAT model considers that the environmental impact (I) is caused by population (P), affluence (A) measured in GDP (per capita), and technology (T) often measured in energy intensity and industrial structure. These relationships are then expressed as:

$$I = PAT. \tag{1}$$

The main advantage of the IPAT model is a simple specification of the three driving forces causing the environmental impact. Furthermore, this equation means that the environmental impacts are the multiplicative products of the driving forces, P, A and T.

Waggoner and Ausubel (2002) extend the IPAT model to the ImPACT model, where T in the IPAT model is decomposed into consumption per unit of GDP (C) and impact per unit of consumption (T). On the other hand, some studies point out the problems of the IPAT and ImPACT equations. They argue that these models are not suitable for testing hypothesis since they are identical equations. Furthermore, they do not allow for non-monotonic or non-proportional effects from the driving forces.

To overcome these problems, the IPAT model is reformulated to the stochastic version, the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model proposed by Dietz and Rosa (1997). The STIRPAT model is specified as follows:

$$I_i = \alpha P_i^{\beta} A_i^{\gamma} T_i^{\delta} \varepsilon_i, \tag{2}$$

where α, β, γ and δ are parameters and ε is the random error term.

A number of researches on the relationship between human activities and CO_2 emissions have been conducted by employing the IPAT, ImPACT and STIRPAT models in recent years.[6] Shi (2003) analyzes the effects of population growth on CO_2 emissions for 93 countries and demonstrates that its impact is more than proportional. York et al. (2003) extend the STIRPAT model by introducing the concept of ecological elasticity and examine the effects on CO_2 emissions and energy footprint. Cole and Neumayer (2004) investigate the impact of demographic factors on CO_2 and sulfur dioxide (SO_2) emissions. They add urbanization, age

[6] Another strand of researches is the environmental Kuznets curve (EKC) hypothesis for CO_2 emissions (e.g., Shafik 1994; Holtz-Eakin and Selden 1995; Soytas et al. 2007).

groups and household size as demographic factors and find different results of their impacts on CO_2 and SO_2 emissions. Martínez-Zarzoso et al. (2007) show that the impact of population growth on CO_2 emissions is different between old EU members and recent EU accession countries. As previously mentioned, Grunewald and Martínez-Zarzoso (2009) study the impact of the Kyoto Protocol on CO_2 emissions.[7]

3 Empirical Analysis

3.1 Estimation methodology and data

To examine the effects of the Kyoto Protocol commitments on various greenhouse gas emissions, our study uses the STIRPAT model, taking into account the role of the Kyoto Protocol. By taking the logarithm of equation (2) and adding the variable representing the Kyoto Protocol, our estimation equation is specified as:

$$\ln I_{it} = \alpha_0 + \beta \ln P_{it} + \gamma \ln A_{it} + \ln T_{it} + \theta Commitment_{it} + e_{it}, \quad (3)$$

where i and t are the country identity and the time series; $\alpha_0 = \ln \alpha$; I is various greenhouse gas emissions such as CO_2, CH_4, N_2O, and other greenhouse gas (HFCs, PFCs and SF_6) emissions; P is total population or urbanization; A is GDP per capita; T is energy intensity, defined as the share of energy use on GDP, and the percentage of value added from the manufacturing sector in total value added; *Commitment* is a dummy variable, which is one after the year countries ratified the Kyoto Protocol and approved to meet quantified emission limitation or reduction commitments; and e is the random error term. The details of the data definitions and sources are illustrated in Appendix A2.

Our sample includes data from 1990, 1995, 2000 and 2005 in 119 countries which are listed in Appendix A1, because data on GHG emissions other than CO_2 are available only for these years. Note that 1990 is used as the base year because the Kyoto Protocol set the target of emission limitation or reduction based on the emission levels of this year. In addition, employing the same equation, our study tries to estimate the effects of the Kyoto Protocol on CO_2 emissions from 1990 to 2005, because annual data for CO_2 emissions are continuously available over that period.

3.2 Estimation results

Table 1 presents the results on CO_2 emissions using the data in 1990, 1995, 2000 and 2005. Columns (1), (2) and (3) report the results of the pooled ordinary least squares (OLS), Fixed Effects (FE) and Random Effects (RE) estimations, respectively. The F, Breusch-Pagan and

[7]Several studies using the STIRPAT model can be found on the environmental impacts other than CO_2. As one of them, Cramer (1998) analyzes five air pollutants such as reactive organic gases (ROG), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), carbon monoxide (CO) and particulate matter (PM_{10}) in California.

Hausman tests show that the FE estimation is appropriate. The coefficient of population is significant and approximately unity, implying that CO_2 emissions are proportional to population. This result is consistent with that of previous studies such as York et al. (2003), Cole and Neumayer (2004) and Grunewald and Martínez-Zarzoso (2009). Since the effect of GDP per capita is significantly positive, CO_2 emissions increase with economic development. Energy intensity and manufacture ratio have positive impacts on CO_2 emissions. *Commitment* is our main interest and is significantly negative, suggesting that the emission limitation or reduction obligations of the Kyoto Protocol have reducing effects on CO_2 emissions. In columns (4), (5) and (6), urbanization is added as the explanatory variable. Since the coefficient of urbanization is significantly positive, as more people live in urban areas, CO_2 emissions increase. In these columns, the coefficient of commitments is still significantly negative. The Kyoto Protocol has been criticized because the US has not ratified it and because reduction targets may not be sufficient to prevent global warming. However, our results indicate that the Kyoto Protocol has a reducing effect on CO_2 emissions although it may not yet be sufficient.

The results of CH_4 emissions are presented in Table 2 and the RE estimation is appropriate from the results of the specification tests. The signs of each variable are the same as those for the case of CO_2 emissions but the impacts of GDP per capita and energy intensity are smaller. This result may be due to the fact that most CH_4 emissions are from the agricultural sector. Since the coefficient of the commitments is significantly negative, the Kyoto Protocol has reducing effects on CH_4 emissions similar to the case of CO_2 emissions.

The estimation results of N_2O emissions are reported in Table 3. Judging from the specification tests at 10% significant level, the FE estimations are suitable. The important difference from the cases of CO_2 and CH_4 is that the coefficient of the commitments is negative but not significant. The smaller impact of GDP per capita and energy intensity may be attributed to the main emissions source being the agricultural sector, similar to CH_4 emissions.

Table 4 provides the estimation results of other greenhouse gas (HFCs, PFCs and SF_6) emissions.[8] The results of the specification tests indicate that the FE estimation is appropriate. The coefficients of population and GDP per capita are not significant by the FE estimations. The remarkable results are that the coefficient of the commitments to the Kyoto Protocol is significantly positive unlike the case of CO_2, CH_4, and N_2O emissions. These results may be caused by the Montreal Protocol taken into effect in 1989, which has regulated the use of chemicals such as chlorofluorocarbons (CFCs) leading to depletion of the ozone layer. Following the Montreal Protocol, the introduction of HFCs which are the alternative for CFCs might have been promoted in many developed countries, most of which ratified the Kyoto Protocol and approved to meet the emission limitation or reduction commitments.

[8] Since many elements of the data of other greenhouse gas (HFCs, PFCs and SF_6) emissions are zero, we take the logarithm after adding one to their values. The estimation results by using the variable taken in logarithm without adding one are slightly different, but the coefficient of commitments to the Kyoto Protocol is significantly positive similar to the results in Table 4.

From the comparison of the estimation results of CO_2, CH_4, N_2O, and other greenhouse gas (HFCs, PFCs and SF_6) emissions, our main and interesting findings are the differences of signs and significance of the commitments to the Kyoto Protocol. The estimations results show that the effects of the commitments to the Kyoto Protocol (1) are significantly negative for the case of CO_2 and CH_4 emissions, (2) are not significant for the case of N_2O emissions and (3) are significantly positive for the case of other greenhouse gas emissions. The Kyoto Protocol has an influence on the reduction in CO_2 and CH_4 emissions, but not in N_2O and other greenhouse gas emissions. These findings have important policy implications for global warming issues. For example, our estimation results indicate that the Kyoto Protocol has increasing effects on other greenhouse gas (HFCs, PFCs and SF_6) emissions. According to IPCC (2007c), the anticipated emissions of F-gas (named as other greenhouse gas in our paper) will increase in the future. In addition, Velders et al. (2009) conjecture the transitions of HFCs emissions till 2050. They show that HFCs emissions may rapidly increase especially in developing countries and its warming effects will become larger. Therefore, in dealing with global warming issues, it might be useful to take into account the effects of these gases in policymaking.

Previous studies on these problems tend to focus on CO_2 emissions. It is true that the contribution of the overall amount of CO_2 emissions on global warming is the highest among GHG emissions, but the other GHG emissions should not be overlooked. Although they are in lesser amounts, their GWPs are much higher than that of CO_2. As for other variables than the commitments, while all GHG emissions are generally proportional to population, urbanization does not have significant effects on CH_4, N_2O, and other greenhouse gas (HFCs, PFCs and SF_6) emissions. Broadly speaking, the effects of GDP per capita and energy intensity are significantly positive on CO_2, CH_4, and N_2O emissions, and these impacts are larger in the corresponding order of CO_2, CH_4, and N_2O emissions.

Since the annual data of CO_2 emissions are continuously available from 1990 to 2005, our study tries to conduct further analysis on CO_2 emissions and provides the estimation results in Table 5. The results in columns (1)-(3) and (5)-(7) correspond to those in columns (1)-(3) and (4)-(6) in Table 1 by using the same estimation methods. These results are almost the same as those in Table 1, implying that our analysis and findings are robust for sample size. Given the sample size of 16 years, we can apply the dynamic panel analysis for our estimation. Columns (4) and (8) report the results by employing the system GMM estimation proposed by Blundell and Bond (1998). The system GMM is appropriate for the analysis on data of small time periods and a large number of countries, and deals with endogeneity bias arising from omitted variables and/or the correlation between explanatory variables and error term by using the instrumental variables. To check the consistency of the system GMM estimator which depends on the validity of the instrumental variables, we use the Hansen test of over-identifying restrictions and the Arellano-Bond test of whether the difference error term is second-order serially correlated. From the results of the Hansen test in columns

(4) and (8), we cannot reject the null hypothesis that the instruments are exogenous, and the Arellano-Bond test shows no second-order serial correlation of the differenced residual. Although the coefficients of manufacture and urbanization are not significant, the log-run impacts of other variable are almost the same as the results by other estimation methods.[9] The effects of commitments to the Kyoto Protocol, which are our main interest, are still significantly negative. Therefore, the dynamic panel analysis provides evidence supporting our main findings.

4 Conclusion

Global warming will have serious negative effects over generations and it is important that greenhouse gas (GHG) emissions be reduced to achieve sustainable development. Genuine saving (GS) is one of the indicators of sustainability and an increase in CO_2 emissions worsens these values. The Kyoto Protocol, adopted in 1997, is an international agreement aiming to reduce GHG emissions. Therefore, investigating the effects of the Kyoto Protocol can provide policy implications for global warming issues and contribute to the researches on sustainable development.

Our study empirically investigates the effects of the Kyoto Protocol's quantified emission limitation or reduction commitments on various greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other greenhouse gas (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6)) emissions. These GHG emissions are considered to be the main source of global warming issues and 39 countries excluding the US, most of which are developed countries, ratified the Kyoto Protocol and approved to meet the commitments. Our empirical analysis is based on the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model, the stochastic version of the IPAT model. Our sample consists of 119 countries in 1990, 1995, 2000 and 2005. In addition, we use the annual continuous data of CO_2 emissions from 1990 to 2005 to check the robustness of our analysis.

Our main findings are that the Kyoto Protocol has a significant reducing effect on CO_2 and CH_4 emissions, an insignificant effect on N_2O emissions and a significant increasing effect on other greenhouse gas emissions. These results have important policy implications for global warming issues. Previous studies on these problems tend to merely focus on CO_2 emissions. It is true that the contribution of the overall amount of CO_2 emissions on global warming is the highest among GHG emissions, but the other GHG emissions should not be overlooked. Although they are in lesser amounts, their global warming potentials are much higher than that of CO_2 emissions. Therefore, in addressing the global warming issues, policymakers should consider the effects of all GHGs.

[9] For example, the long-run impact of population is calculated form (the coefficient of population) / (1 - the coefficient of CO_2(-1)).

Acknowledgements

We are grateful to Kazuki Kagohashi and Sovannroeun Samreth for numerous helpful comments and discussion. We are however solely responsible for any mistakes in this paper.

Appendix

A1. Countries in the samples

As of 2009, 194 countries and regions have ratified the United Nations Framework Convention on Climate Change (UNFCCC). Of these countries and regions, 39 countries and the European Union (EU) have ratified the Kyoto Protocol and have approved to meet quantified emission limitation or reduction commitments, which are legally binding. They are listed as the countries with commitments to the Kyoto Protocol as follows. The numbers in parentheses are the years when each country ratified the Kyoto protocol.

Australia (2007), Austria (2002), Belarus (2005), Belgium (2002), Bulgaria (2002), Canada (2002), Croatia (2007), Czech Republic (2001), Denmark (2002), Estonia (2002), Finland (2002), France (2002), Germany (2002), Greece (2002), Hungary (2002), Iceland (2002), Ireland (2002), Italy (2002), Japan (2002), Latvia (2002), Liechtenstein (2004), Lithuania (2003), Luxembourg (2002), Monaco (2006), Netherlands (2002), New Zealand (2002), Norway (2002), Poland (2002), Portugal (2002), Romania (2001), Russia (2004), Slovak Republic (2002), Slovenia (2002), Spain (2002), Sweden (2002), Switzerland (2003), Turkey (2009), Ukraine (2004), United Kingdom (2002), European Union (2002).

Our sample does not include the European Union (EU) which also ratified the Kyoto protocol, because the aim of our study is to focus on country-level analysis. Note that Turkey ratified the Kyoto Protocol but has not yet set its target value. The commitments of Belarus and Turkey have not been officially approved as a treaty because the Kyoto Protocol has not been revised. Due to data limitation, Australia, Liechtenstein, Monaco, Sweden and Switzerland are excluded from our analysis.

Next, 150 countries have ratified the Kyoto protocol but have not yet approved to meet quantified emission limitation or reduction commitments, and 4 countries have not ratified the Kyoto Protocol. Because of data availability, the following 85 countries are included in our sample as countries without commitments to the Kyoto Protocol. Since data of greenhouse gas emissions other than CO_2 emissions in Macedonia is unavailable, the number of countries is different among the estimations.

Albania, Algeria, Angola, Argentina, Armenia, Azerbaijan, Bahrain, Bangladesh, Benin, Bolivia, Botswana, Brazil, Brunei Darussalam, Cambodia, Cameroon, Chile, China, Colombia, Congo (Democratic Republic), Congo (Republic), Costa Rica, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Eritrea, Ethiopia, Gabon, Georgia, Ghana, Guatemala, Haiti, Honduras, India, Indonesia, Iran, Jamaica, Jordan, Kazakhstan, Kenya, Korea (South), Kuwait, Kyrgyz, Lebanon, Macedonia, Malaysia, Malta, Mexico, Moldova, Mongolia, Morocco, Mozambique, Namibia, Nepal, Nicaragua, Nigeria, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Saudi Arabia, Senegal, Singapore, South Africa, Sri Lanka, Sudan, Syria, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkmenistan, United Arab Emirates, United States, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zambia.

A2. Data sources and descriptions

Our sample includes 119 countries in 1990, 1995, 2000 and 2005. In addition, annual continuous data of CO_2 emissions from 1990 to 2005 is included for further analysis to check the robustness. Note that 1990 is used as the base year because the Kyoto Protocol set the target of emission limitation or reduction based on the emissions level of this year. All data are obtained from the World Development Indicators (WDI) 2009 CD-ROM released by the World Bank (2009).

The dependent variables are CO_2, CH_4, N_2O and other greenhouse gas (HFCs, PFCs and SF_6) emissions. CO_2 emissions are measured as kilogram tons. CH_4 emissions and other greenhouse gas emissions are measured as kilogram tons of CO_2 equivalent. N_2O emissions are measured as thousand metric tons of CO_2 equivalent.

The explanatory variables are population, urbanization, GDP per capita, energy intensity, manufacture and commitments. Population is mid-year estimates. Urbanization is measured as the percentage of urban population in the total population. GDP per capita is real GDP per capita measured at purchasing power parity in 2005 international dollars. Energy intensity is defined as the share of energy use in real GDP. Manufacture is the percentage of value added from the manufacturing sector in the total value added. *Commitment* is a dummy variable which is one after the year countries ratified the Kyoto Protocol and approved to meet quantified emission limitation or reduction commitments.

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Table 1: The effects on carbon dioxide (CO_2) emissions

	(1) OLS	(2) FE	(3) RE	(4) OLS	(5) FE	(6) RE
Population	1.028***	1.185***	1.020***	1.032***	0.928***	1.010***
	(0.019)	(0.103)	(0.031)	(0.019)	(0.133)	(0.030)
Urbanization				0.311***	0.654***	0.446***
				(0.081)	(0.218)	(0.113)
GDP per capita	1.334***	0.948***	1.222***	1.251***	0.863***	1.098***
	(0.029)	(0.076)	(0.040)	(0.036)	(0.080)	(0.051)
Energy intensity	0.895***	0.476***	0.717***	0.911***	0.464***	0.701***
	(0.055)	(0.089)	(0.066)	(0.054)	(0.088)	(0.065)
Manufacture	0.281***	0.211***	0.186***	0.251***	0.205***	0.187***
	(0.055)	(0.051)	(0.045)	(0.054)	(0.050)	(0.045)
Commitment	-0.337***	-0.115**	-0.144***	-0.313***	-0.105**	-0.123***
	(0.110)	(0.048)	(0.047)	(0.109)	(0.047)	(0.047)
Constant	-5.154***	-10.632***	-6.532***	-5.410***	-8.438***	-7.315***
	(0.814)	(2.054)	(1.042)	(0.803)	(2.154)	(1.043)
F test	25.15***			24.92***		
BP test	367.46***			369.71***		
Hausman test			21.15***			18.86***
R^2	0.92	0.85	0.92	0.92	0.91	0.92
Observations	413	413	413	413	413	413
No. of countries	119	119	119	119	119	119

Notes:

1. All variables are taken in logarithm.
2. The asterisks ***, ** and * are 1%, 5% and 10% of significant levels, respectively.
3. The numbers in parentheses are standard errors.

Table 2: The effects on methane (CH_4) emissions

	(1) OLS	(2) FE	(3) RE	(4) OLS	(5) FE	(6) RE
Population	0.968***	0.977***	0.961***	0.969***	0.841***	0.959***
	(0.025)	(0.132)	(0.040)	(0.025)	(0.173)	(0.040)
Urbanization				0.039	0.348	0.103
				(0.106)	(0.284)	(0.148)
GDP per capita	0.335***	0.247**	0.290***	0.324***	0.202*	0.261***
	(0.037)	(0.097)	(0.052)	(0.047)	(0.104)	(0.066)
Energy intensity	0.318***	0.428***	0.417***	0.320***	0.422***	0.413***
	(0.071)	(0.114)	(0.084)	(0.071)	(0.114)	(0.084)
Manufacture	-0.306***	-0.036	-0.080	-0.310***	-0.040	-0.080
	(0.071)	(0.065)	(0.057)	(0.072)	(0.065)	(0.057)
Commitment	-0.466***	-0.141**	-0.172***	-0.463***	-0.136**	-0.167***
	(0.143)	(0.061)	(0.059)	(0.143)	(0.061)	(0.059)
Constant	-3.486***	-1.949	-2.124	-3.518***	-0.772	-2.299*
	(1.054)	(2.631)	(1.331)	(1.059)	(2.799)	(1.358)
F test	25.80***			25.85***		
BP test	369.32***			369.05***		
Hausman test			6.64			7.60
R^2	0.80	0.78	0.79	0.80	0.78	0.79
Observations	409	409	409	409	409	409
No. of countries	118	118	118	118	118	118

Notes:

1. All variables are taken in logarithm.
2. The asterisks ***, ** and * are 1%, 5% and 10% of significant levels, respectively.
3. The numbers in parentheses are standard errors.

Table 3: The effects on nitrous oxide (N_2O) emissions

	(1) OLS	(2) FE	(3) RE	(4) OLS	(5) FE	(6) RE
Population	0.949***	1.291***	0.993***	0.956***	1.497***	0.987***
	(0.028)	(0.163)	(0.047)	(0.028)	(0.213)	(0.047)
Urbanization				0.495***	-0.528	0.258
				(0.119)	(0.352)	(0.176)
GDP per capita	0.119***	0.217*	0.188***	-0.012	0.285**	0.116
	(0.043)	(0.120)	(0.062)	(0.053)	(0.128)	(0.079)
Energy intensity	-0.226***	0.301**	0.064	-0.200**	0.310**	0.052
	(0.081)	(0.141)	(0.101)	(0.080)	(0.141)	(0.101)
Manufacture	-0.090	0.057	0.043	-0.136*	0.063	0.042
	(0.082)	(0.081)	(0.070)	(0.081)	(0.081)	(0.070)
Commitment	-0.077	-0.101	-0.136*	-0.039	-0.109	-0.124*
	(0.163)	(0.076)	(0.073)	(0.160)	(0.076)	(0.074)
Constant	-10.751***	-9.523***	-8.005***	-11.157***	-11.259***	-8.478***
	(1.206)	(3.261)	(1.596)	(1.186)	(3.453)	(1.621)
F test	21.80***			20.91***		
BP test	337.18***			313.20***		
Hausman test			9.37*			14.80**
R^2	0.75	0.73	0.74	0.76	0.71	0.75
Observations	408	408	408	408	408	408
No. of countries	118	118	118	118	118	118

Notes:

1. All variables are taken in logarithm.
2. The asterisks ***, ** and * are 1%, 5% and 10% of significant levels, respectively.
3. The numbers in parentheses are standard errors.

Table 4: The effects on other greenhouse gas (HFCs, PFCs and SF_6) emissions

	(1) OLS	(2) FE	(3) RE	(4) OLS	(5) FE	(6) RE
Population	1.461***	0.446	1.317***	1.470***	0.632	1.316***
	(0.064)	(0.453)	(0.109)	(0.064)	(0.594)	(0.109)
Urbanization				0.618**	-0.476	0.200
				(0.272)	(0.976)	(0.442)
GDP per capita	2.164***	-0.330	1.714***	2.000***	-0.269	1.659***
	(0.096)	(0.333)	(0.151)	(0.120)	(0.356)	(0.196)
Energy intensity	1.262***	-2.099***	0.216	1.294***	-2.091***	0.216
	(0.183)	(0.392)	(0.263)	(0.182)	(0.393)	(0.263)
Manufacture	0.761***	-0.106	0.096	0.702***	-0.100	0.094
	(0.184)	(0.224)	(0.200)	(0.185)	(0.225)	(0.200)
Commitment	1.187***	0.619***	0.709***	1.235***	0.611***	0.720***
	(0.368)	(0.210)	(0.222)	(0.367)	(0.211)	(0.223)
Constant	-21.460***	-32.405***	-29.328***	-21.967***	-34.014***	-29.630***
	(2.717)	(9.027)	(4.054)	(2.712)	(9.624)	(4.117)
F test	13.50***			13.27***		
BP test	240.36***			232.99***		
Hausman test			143.18***			143.20***
R^2	0.74	0.05	0.70	0.74	0.07	0.71
Observations	409	409	409	409	409	409
No. of countries	118	118	118	118	118	118

Notes:

1. All variables are taken in logarithm except for other greenhouse gas emissions, which are equal to log (1+ their value).
2. The asterisks ***, ** and * are 1%, 5% and 10% of significant levels, respectively.
3. The numbers in parentheses are standard errors.

Table 5: The effects on carbon dioxide (CO_2) emissions (Annual data from 1990 to 2005)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	FE	RE	system GMM	OLS	FE	RE	system GMM
Population	1.033***	1.342***	1.064***	0.237**	1.039***	1.002***	1.037***	0.284**
	(0.010)	(0.076)	(0.029)	(0.097)	(0.010)	(0.100)	(0.029)	(0.120)
Urbanization					0.337***	0.858***	0.656***	0.073
					(0.042)	(0.165)	(0.096)	(0.079)
GDP per capita	1.342***	1.061***	1.256***	0.291**	1.252***	0.952***	1.081***	0.331**
	(0.015)	(0.056)	(0.035)	(0.126)	(0.018)	(0.059)	(0.043)	(0.140)
Energy intensity	0.947***	0.758***	0.864***	0.219**	0.960***	0.731***	0.820***	0.271**
	(0.028)	(0.061)	(0.050)	(0.110)	(0.028)	(0.060)	(0.050)	(0.136)
Manufacture	0.301***	0.122***	0.114***	0.040	0.265***	0.117***	0.117***	0.040
	(0.029)	(0.034)	(0.032)	(0.029)	(0.029)	(0.034)	(0.032)	(0.030)
Commitment	-0.331***	-0.087***	-0.110***	-0.068***	-0.302***	-0.077***	-0.089***	-0.070***
	(0.058)	(0.030)	(0.029)	(0.025)	(0.057)	(0.029)	(0.029)	(0.026)
CO_2(-1)				0.771***				0.727***
				(0.094)				(0.115)
Constant	-4.578***	-9.627***	-5.116***	-0.797*	-4.921***	-6.915***	-6.428***	-0.950
	(0.417)	(1.475)	(0.835)	(0.479)	(0.411)	(1.553)	(0.843)	(0.582)
F test	65.46***				63.84***			
BP test	7049.91***				7107.82***			
Hausman test			25.27***				3.08	
Hansen test				53.10				51.98
AR(2) test				0.38				0.38
R^2	0.92	0.84	0.91		0.92	0.91	0.91	
Observations	1681	1681	1681	1669	1681	1681	1681	1669
No. of countries	119	119	119	119	119	119	119	119

Notes:

1. All variables are taken in logarithm.
2. The asterisks ***, ** and * are 1%, 5% and 10% of significant levels, respectively.
3. The numbers in parentheses are standard errors.
4. In columns (4) and (8), time dummies are included but their results are not reported.