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1. Introduction

The greenhouse effect, the main driver of global warming, is a natural phenomenon, but human activities such as fossil fuel combustion and land use (particularly deforestation) are exacerbating it in ways unprecedented over the last 10,000 years. The Intergovernmental Panel on Climate Change (IPCC) claims that the average temperature of the earth's surface has risen by 0.74^{o} C since the late 1800s, and this trend is expected to accelerate by 1.8^{o} C and 4^{o} C by 2100 if no remedial action is taken (Solomon et al. 2007). As a result, the sustainability of the earth is being threatened by a number of devastating processes: the melting polar ice caps, flooding coastlines, severe storms, changes in precipitation patterns, and widespread changes in the ecological balance.

The main international effort to combat global warming is the United Nations Framework Convention on Climate Change (UNFCCC), an international environmental treaty that took effect on March 21, 1994, with 194 parties participating as of May 2011. The ultimate objective of this treaty is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.[1] While this treaty is legally non-binding and thus enforces no compulsory emission limits, it provides protocols that would set mandatory emission limits. The principal update of this initiative is the Kyoto Protocol, which came into effect on February 16, 2005, with 191 states (excluding the U.S.) among major signatories. The parties to the UNFCCC are classified into three groups according to their phase of economic development and whether they are paying the costs needed to help developing countries attain their goals.[2] Under the Protocol, Annex I countries commit themselves to reducing greenhouse gas (GHG)[3] by 5.2% of 1990 levels for the first commitment period (2008 to 2012).[4]

One of the contributions of this research is its application of the advantageous securitization mechanism to CO_2 emission reduction. We design the securities based on the CO_2 emissions produced by the main emitting countries and illustrate the premium calculation by using CO_2 emissions data. The security issuer would facilitate the securing of funds from capital markets for direct investment into CO_2 emissions reduction. The securities could be sold to sovereign wealth funds, mutual funds, institutional investors, or normal investors, which would increase the attention paid to the CO_2 emissions that decide the size of the securities' premiums. This attention would turn public opinion against any increase in the CO_2 emissions of the main emitting countries. Investors could thus indirectly reduce emissions by simply holding the securities. Naturally, this securitization mechanism can be applied to any harmful gas. This proposal would provide investors with diversified investment opportunities in line with their risk–return profiles.

This study also proposes "green spread," a financial environmental cleanliness measure for each country, in the form of the coupon rate of a single tranche. This measure would give investors an investment barometer and offer each country an incentive to reduce its CO_2 emissions.

The Kyoto Protocol outlines three flexible mechanisms with which the overall costs of accomplishing emission reduction targets can be lowered: emissions trading (ET), the clean development mechanism (CDM) and joint implementation (JI).[5] The ET mechanism is a market-based cap-and-trade scheme in which a regulatory authority enforces a limit (or "cap") on emissions and then allocates or sells permits for emissions to firms. The permits are called "assigned amount units" (AAUs) and are tradable domestically or across nations that have ratified the Protocol. While the ET is a market-based mechanism, the CDM and JI are project-based mechanisms. An Annex I country is eligible to acquire other forms of emission permits if it finances an emission-reduction project in a non-Annex I country under the CDM framework or in another Annex I country under JI. The permits created by CDM and JI projects are called

[1] Article 2, The United Nations Framework Convention on Climate Change, http://unfccc.int/essential_back ground/convention/background/items/1353.php, Retrieved on November 09, 2011.

[2] Industrialized countries and economies in transition are in Annex I, and a subgroup of these that satisfy the second condition is also in Annex II; a country can be included in both Annex I and Annex II. Developing countries are categorized as non-Annex I countries; 37 countries are categorized as Annex I countries.

[3] The reduction target applies to four greenhouse gases (i.e., carbon dioxide, methane, nitrous oxide, and sulphur hexafluoride) and two types of gases (i.e., hydrofluorocarbons and perfluorocarbons) produced by the former through translation into CO_2 equivalents. The target is set in addition to the industrial gases (i.e., chlorofluorocarbons or CFCs) under the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, while international aviation and shipping are not included.

[4] Mandatory reduction targets after the first commitment period are yet to be set despite ongoing negotiations.

[5] For further details, see Hepburn (2007).

"certified emission reductions" (CERs) and "emission reduction units" (ERUs) respectively. The trading of these permits occurs during climate exchanges, which provide a spot market as well as futures and an option market.[6]

The European Union Emission Trading Scheme (EU ETS) and the New Zealand Emissions Trading Scheme (NZ ETS) are the only mandatory emission trading mechanisms; similar initiatives in other countries have been halted or delayed.[7] The EU ETS, launched by the 25 EU countries on January 1, 2005, covers only carbon dioxide (CO_2), including over 11,000 installations; it covers almost half of Europe's CO_2 emissions (Hepburn 2007). The NZ ETS entered into force on July 1, 2010, and aimed to reduce the carbon price to NZ$12.50 until December 31, 2012.[8] The global carbon market stagnated in 2010 at the market value of US$141.9 billion after it recorded consecutive periods of robust growth from 2005 to 2009; the market value had grown dramatically, from US$11 billion in 2005 to US$143.7 billion in 2009.[9] An important feature of this market is the increased dominance of the European Union Allowances (EUAs) market, the value of which grew from US$7.9 billion in 2005 to US$119.8 billion in 2010 constituting 84 percent of the global market value (Linacre et al. 2011).[10] In 2009, a total of US$119 billion worth of allowances and derivatives were traded in the EU ETS, 73 percent of which comprised futures contracts, while the carbon options market reached US$10.6 billion in value (Kossoy and Ambrosi 2010).

A well-functioning market is crucial for successful ET implementation because it is the market under which any movement or volatility in carbon prices is determined. Market efficiency can be improved by introducing carbon derivatives, since these instruments serve as price discovery tools and provide liquidity in the market. Globally, around 84 percent of financial derivatives were over-the-counter (OTC) products in June 2007, and the carbon derivative market is no exception.[11] The key advantages of these OTC contracts are customizability and flexibility; counterparty credit risk can be significant in the absence of a clearing house, and liquidity is limited, especially for exotic risks such as the risk of interest in this paper—GHG emission allowance. Among various noble approaches to constructing derivative products, securitization has been gaining in popularity since its introduction in the late 1970s.[12] In principle, counterparty credit risk can be eliminated by establishing a special entity for cash flow administration that is independent and secured against bankruptcy. The liquidity of these instruments can be improved by structuring their tranches in ways that provide the best possible risk and return profiles to various groups of investors.

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[6] Major climate exchanges include the European Climate Exchange, NASDAQ OMX Commodities Europe, PowerNext, Commodity Exchange Bratislava, and the European Energy Exchange.

[7] Federal cap-and-trade legislation is not supported in the U.S. The Japanese government lost control of the upper house, and the Japanese Basic Act on Global Warming was stalled. The Australian government chose to freeze a domestic trading scheme, and the Republic of Korea's scheme is delayed until 2015 (Linacre et al. 2011).

[8] Emissions trading bulletin No 11: Summary of the proposed changes to the NZ ETS, http://www.mfe.govt.nz/publications/climate/emissions-trading-bulletin-11/, Retrieved on November 14, 2011.

[9] Markets for the primary CDM, the U.S. Regional Greenhouse Gas Initiative (RGGI), and the assigned amount unit (AAU) were main drivers of the stagnation. The primary CDM market fell from US$2.7 billion to US$1.5billion due to regulatory uncertainty after 2012. The latter two markets dropped from US$4.3billion to US$1.1billion collectively, partly because federal cap-and-trade legislation failed to receive enough support.

[10] If the secondary CDM is taken into account, the proportion of the EU ETS rose to 97 percent.

[11] Please refer to Deutsche Börse and Eurex (2008).

[12] Securitization is the process of pooling the assets, liabilities, or cash flows of an issuer or issuers and conveying them to third parties after tranching according to the levels of risk exposure (Banks 2004).

The rest of this paper is organized as follows. Section 2 surveys the relevant literature. Section 3 explains the current status of EU ETS in terms of GHG reduction. Section 4 discusses CO_2 emission modeling along with the Kyoto protocol and data. Section 6 describes the securitization underlying the CO_2 emissions of several countries and the pricing of the securities' premiums. Section 7 concludes the paper with a brief summary and presentation of the main results.

2. Literature Survey

Like all pollution, CO_2 emissions are a kind of negative externality, due to which market prices do not reflect the full costs, as they exclude the impacts of global warming. Emitters thus gain excessive benefits while undermining the welfare of future generations and threatening the environment. Seeking to internalize these external costs, academics, policy makers, and regulators have been focusing on market-based emission reduction mechanisms. Unlike prescriptive command-and-control regulation, market-based mechanisms provide participants with economic incentives to comply, allowing emissions reduction to be achieved more efficiently while producing information on compliance procedures more transparently and also encouraging the development of alternative reduction technologies more actively. Furthermore, regulatory bodies can provide crucial assistance by enforcing emissions allowance allocations. The EU ETS is the world's largest multinational greenhouse gas emissions trading scheme. Covering only carbon dioxide (CO_2), it includes over 11,000 installations. Under this scheme, the right to emit (i.e., an allowance) is allocated as a "European Union Allowance" (EUA); 1 unit of EUA is equivalent to 1 ton of CO_2. These EUAs are treated as commodities; thus, financial derivatives can be constructed based on them. They are also traded in the spot market. The primary concerns of market participants in the spot and derivative markets such as risk management consultants, brokers, and traders are the price behavior and dynamics of this new asset class, CO_2 emission allowances in general and EUAs in particular. The concept of modeling and pricing CO_2 derivatives discussed in this paper differs from the conventional approach to environmental economics and policy studies.

Most of the empirical research on the price behavior and dynamics of allowances is based on the EU ETS since this scheme is rich in liquidity and has a well-developed market mechanism. It is important to note that the scheme's Phase I (2005–2007) and Phase II (2008–2012) should be considered separately in analyses of price behavior due to differences between the market developments. Early studies fail to show consistent results about market efficiency. For example, Uhrig-Homburg and Wagner (2007) found that futures contracts whose maturities expire within Phase I reveal the cost of carry pricing mechanism, while Truck et al. (2007) showed that convenient yield is statistically significant among futures contracts that mature in Phase II. Furthermore, the weak form of market efficiency hypothesis is rejected with spot and futures price data from the Powernext, Nord Pool and EXC because of short-selling and banking restrictions (Daskalakis and Markellos 2008). Moreover, Daskalakis et al. (2005) found that market participants followed conventional no-arbitrage pricing.

Paolella and Taschini (2006) modeled the unconditional tail behavior and heteroskedastic dynamics of CO_2 and SO_2 allowance returns using their econometric structure. The authors found that the unconditional tails can be represented well by the Pareto distribution and the conditional dynamics approximated by a new GARCH-type structure. Benz and Truck (2009) applied a regime-switching model to model the dynamics of the allowance spot price. Chesney and Taschini (2008) constructed an endogenous model to describe the dynamics of the spot price and demonstrated asymmetric information in the market. Seifert et al. (2008) discussed stylized facts of EU ETS data with a stochastic equilibrium model of a typical economic theory, finding that the CO_2 process does not have a seasonal pattern, and thus has a martingale property, but does have a time- and price-dependent volatility structure.

3. EU ETS and Global CO_2 level

This section discusses the current status of GHG reduction efforts by assessing the EU ETS and its impact on GHG reduction. Since the EU ETS is the first and largest GHG emission certificate trading system, we will use it to appraise current efforts to reduce global GHG emissions.

The effectiveness of the EU ETS is a matter of ongoing debate. Its achievements include being the first working emission trading system and obtaining some carbon emissions reductions from participating members. On the other hand, some have criticized it for an excessive flexibility, an overestimation of GHG emissions by many members, superfluous grandfathering (e.g., the granting free-of-charge certificates), the encouragement of fraud and profiteering, and the exclusion of the countries responsible for most of the world's GHG emissions.

First, let us discuss some of the research on the effectiveness of the EU ETS. Martin Muûls and Wagner (2012) performed a thorough search of the literature on the EU ETS, reviewing a total of 179 research papers. Some of these evaluated the EU ETS' effect on CO_2 emissions. Anderson and Di Maria (2011) estimated that there was a 2.8% reduction in CO_2 emissions from BAU (business-as-usual) in Phase I, considered the pilot period for the EU ETS.[13] Anderson and Di Maria (2011) considered various factors affecting CO_2 emissions (such as the economy, weather, and price of electricity) to construct BAU estimates and compared them to actual CO_2 to produce an estimation of 2.8% CO_2 reduction in Phase I. The estimated 2.8% reduction in CO_2 emissions claimed by Anderson and Di Maria (2011) is similar to the claim in Ellerman, Convery, and De Perthuis (2010) that the CO_2 emission reduction in Phase I (2005–2007) was around 3.3% from BAU (or 70 MT per year). Another noteworthy study on EU ETS' impact on CO_2 emission reduction is Abrell, Ndoye, and Zachmann (2011), who matched the firm information database in CITL with AMADEUS[14] to estimate the CO_2 emissions reductions of Phases I and II (2008–2012). Matching CITL data to AMADEUS data was challenging because they had to match the addresses of 3,680 installations (one company may have more than one installation). According to the authors, CO_2 emissions reduction was 3.6% lower in Phase II than in Phase I. However, since Abrell, Ndoye, and Zachmann (2011) did not consider exogenous factors, some of the 3.6% drop in CO_2 emissions seen in Phase II might have been caused by other factors, such as the economy, weather, and energy prices. Martin, Muûls and Wagner (2012) provide more research results on CO_2 emissions reductions during the EU ETS.

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[13] A 2.8% reduction in CO_2 emissions for parties to the EU ETS is equivalent to 58 MT (metric tons) of CO_2 per year.

[14] The CITL is a transaction log for EU emission trading data, and AMADEUS is a commercial database distributed by Bureau Van Dijk to most European firms.

Despite the numerous research findings that support the effectiveness of the EU ETS, its cap-and-trade system has been criticized. For example, Gilbertson and Reyes (2009) have criticized many aspects of the EU ETS.

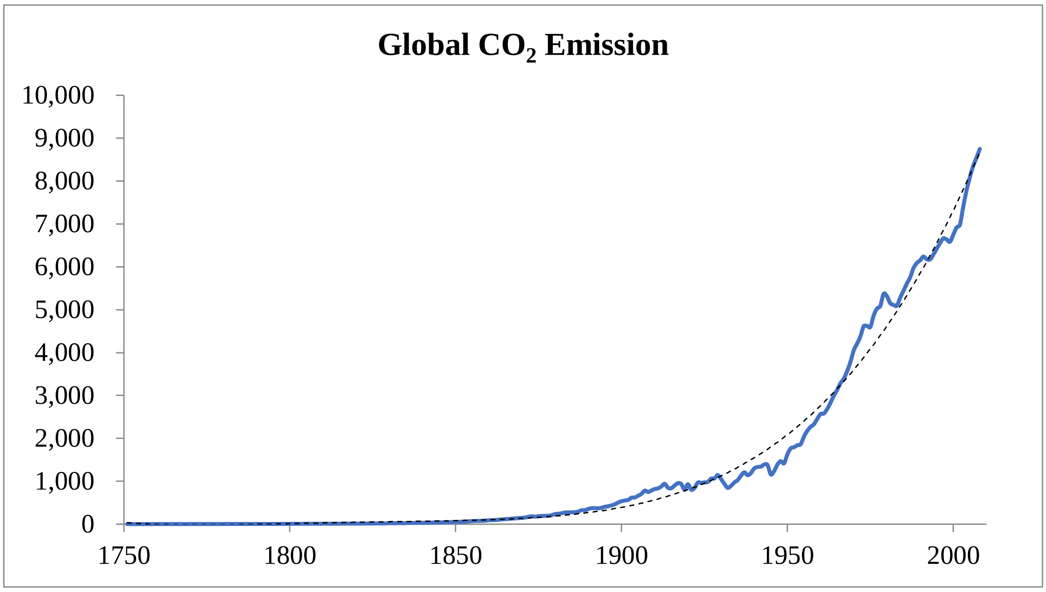
First, they claim that its flexibility allows some of its members to emit more CO_2 rather than strive for reduction. The flexibility of the EU ETS leads to excessive grandfathering (i.e., issuing CO_2 emission certificates free of charge), inaccurate assessments of the CO_2 emissions of participating members, and the use of CDM and JI. Anderson and Di Maria (2011) showed that the EUA quantities for European countries during Phase I were unbalanced: excessive EUA were assigned to some countries and insufficient EUA to others.[15] According to Gilbertson and Reyes (2009), installations that needed to emit more CO_2 could simply purchase certificates from countries with excess permits instead of trying to develop technologies to reduce CO_2 emissions. This tendency to pass the responsibility for reducing CO_2 emissions onto others was worsened by excessive grandfathering.[16] Furthermore, Gilbertson and Reyes (2009) also criticized CDM and JI for sponsoring projects that have failed to improve the environment. Some EU ETS members were also accused of exploiting CDM and JI[17] instead of trying to reduce CO_2 emissions.[18] The fact that purchasing CO_2 emission certificates is usually cheaper than reducing CO_2 emissions for most energy companies has also been criticized.

Despite the criticisms, the EU ETS is the first working GHG emission trading system to help reduce GHG emissions. Viewed from a wider perspective, however, EU ETS' efforts have had an insignificant impact on global GHG levels, largely through the nonparticipation of heavy CO_2 emitters. For example, the Bush government rejected the Kyoto protocol in March 2001 and announced in February 2002 that the U.S. would rely on domestic voluntary action to reduce GHG emitted by the U.S. economy by 18% over the next 10 years[19] (the downward trend in U.S. CO_2 emissions between 2007 and 2009 may be due to the global financial crisis of the same period). In 2010, Canada, Japan, and Russia announced that they would not accept new Kyoto commitments. Canada then withdrew from the Kyoto Accord entirely in December 2011, probably because Canada was not going to be able to avoid paying a $14 billion penalty for failing to meet its goal without repudiating the Accord. Canada also argued that the Kyoto protocol cannot work because the U.S. and China (the world's largest GHG emitters) are not participating in it[20] (China and India, two major GHG emitters, were not included among Annex I countries because they are classified as developing countries).

Figure 1 below shows historical global CO_2 emissions.[21] The dotted line is a fourth-order regression line with R^2=0.989.

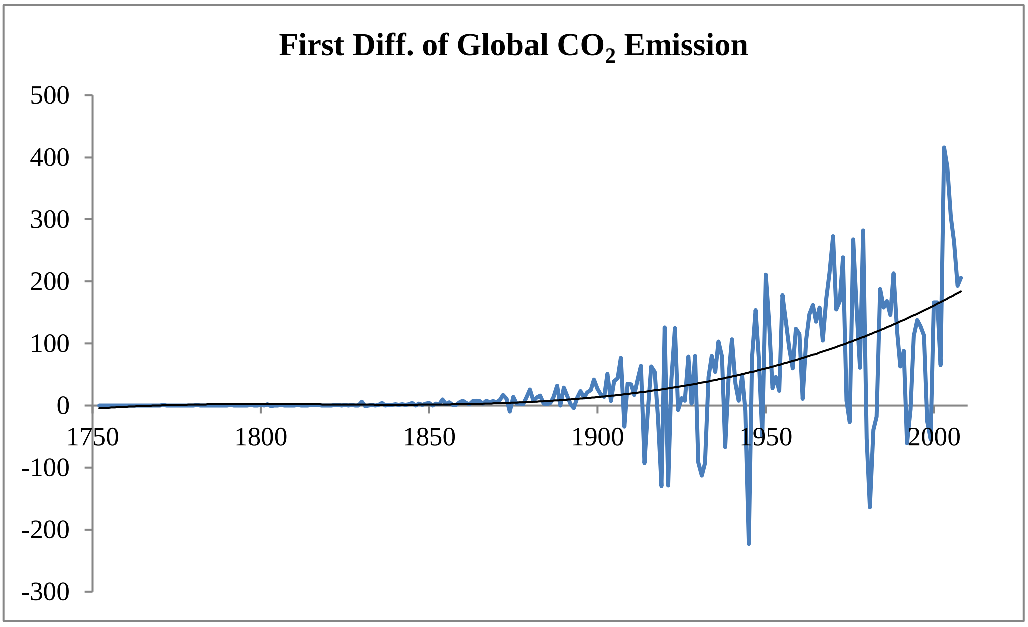
Figure 1: Global CO2 emissions between 1751 and 2008 in metric tons

15 The Czech Republic, France, Germany, and Poland had excess EUA, while Spain, Italy, and the UK did not have enough.
16 The daily closing price of EUA spots plummeted in 2006 and 2007 when EU ETS participants realized that the supply of permits exceeded demand.
17 CDM and CI can be traded for CO_2 emission certificates.
18 Gilbertson and Reyes (2009) also mention that entrepreneurs in India and China built factories whose primary purpose was to produce GHG. These entrepreneurs have made billions of dollars by trading their GHG emissions through CDM and JI.
19 http://www.eoearth.org/article/Kyoto_Protocol_and_the_United_States, an article in *The Encyclopedia of Earth*.
20 "Canada pulls out of Kyoto protocol," *The Guardian* (UK). December 13, 2011.
21 Boden, T.A., G. Marland, and R.J. Andres (2010). Global, Regional, and National Fossil-Fuel CO2 Emissions.



The first differences in yearly CO_2 emissions can be seen in Figure 2. Figures 1 and 2 show that we are emitting around 9,000 million MT of CO_2 each year. It is expected that an additional 200 million MT of CO_2 will soon be emitted each year. As mentioned, Anderson and Di Maria (2011) found a 2.8% reduction in CO_2 emissions from BAU during Phase I of the EU ETS, and Abrell, Ndoye, and Zachmann (2011) estimated that CO_2 emissions reduction was 3.6% lower in Phase II than in Phase I (keeping in mind, as noted, that the latter finding is probably overestimated). As already explained, a 2.8% reduction from BAU in the EU ETS is equivalent to 58 MT per year. Given that global CO_2 emissions per year total around 9,000 million MT, with an additional 200 million MT increase expected each year, we can see that EU ETS' endeavor has a long way to go.

Figure 2: First differences in global CO_2 emissions between 1751 and 2008 in metric tons



We are suggesting a new approach to resolving the global GHG emissions issue—a financial commodity that will restrain the GHG emissions of UNFCCC nations through securitization. This study proposes that the financial markets can settle the external diseconomies of GHG emissions and that scholarly research can solve real-world problems. The advantages of the proposed financial commodity are as follows:

1. The securities pay more coupons when GHG emissions are reduced. Hence, the investors in these securities will try to foster GHG emissions reductions.

2. Governments that invest in these products will have an incentive to reduce GHG emissions, solving problems related to a shrinking CO_2 emissions market and the nonfulfillment of international agreements on carbon emissions.

3. Institutional and private investors will become concerned about carbon emissions, which may lead to concern for the environment.

4. Since the securities have a zero or negative (for Russia) correlation with the financial market, they may help to diversify financial markets.

5. If the GCF (Green Climate Fund) becomes the issuer, these securities would be good tools for helping the GCF raise fund and address GHG emissions reduction.

We need to accurately price and design the correct commodities to obtain sufficient market demand. This task requires analyzing the emissions data from various angles and referring to many studies.

This section has discussed the research on the EU ETS and has indicated that it has been ineffective in reducing the drastically increasing global CO_2 emissions. Global GHG reduction requires the active participation of heavy GHG emitters, the enforcement of international regulations, and the use of both financial and non-financial instruments. This study attempts to develop an effective financial instrument for GHG reduction.

4. CO_2 Emissions Modeling and Expanded Kyoto Protocol

4.1 CO_2 Emissions Modeling

First, global self-immolating reduction efforts are most important for overall CO_2 emissions reduction. The 2011 withdrawal of Canada from the Kyoto Accord shows that international agreement on emissions reduction is not enough; real effort is required. Thus, a mechanism that can induce real reduction efforts among nations is needed. Such a model or financial commodity should be linked to the amount of CO_2 emissions each nation produces and should control this amount. To construct the model, we need national data on CO_2 emissions. Since the financial model should induce emission reductions until a specific time, within a specific amount, the expected emission amounts must be estimated.

The data on CO_2 emissions must be such as to guarantee the clarity and reliability of the measurement. Some subjects, such as animals and trees, are not suitable for use in measuring emissions because they generate obscure measurement problems and are thus not suitable as underlying assets for financial commodities. We therefore limit the subject of CO_2 emissions to fossil fuels. Fossil fuels are not only related to other emitting subjects, such as automobiles and factories, but are also an influenceable factor in total CO_2 emissions. In addition, data on the CO_2 emissions from fuel combustion of all countries are publicly available through international organizations such as the IEA (International Energy Agency) and EIA (Energy Information Administration). We used the IEA's time-series data on CO_2 emissions, ordered by country, covering 1971 to 2010. We also price the security premiums using data on the top three GHGs (i.e., CO_2, CH_4, and N_2O).

For the given time-series data, we need to estimate the expected emissions amount after a few years. Most studies (e.g., Mastrandrea and Schneider 2005; den Elzen and Mainshausen 2006; Jones, Cox and Huntingford 2006) consider much longer periods, such as 100 or 200 years and thus cannot be applied to financial commodities. We will estimate the emission amounts within shorter spans, of fewer than 10 years.

4.2 Expanded Kyoto Protocol

The revision accepted at COP18 (the 18th Conference of the Parties to the UNFCCC) extended the commitment period by three years, making it from 2013 to 2020. If we call α the emission reduction target suggested by the Kyoto Protocol, then Annex 1 countries should reduce their GHG emissions by (1+ α) times their emission amount in 1990.

In 2010, the top 10 CO_2-emitting nations were Canada, China, Germany, India, Iran, Japan, South Korea, Russia, the UK and USA, which emitted 65.50% of the world's CO_2. Among these, the Annex 1 nations were Canada, Germany, Japan, Russia, and the UK. Though Canada withdrew, this paper will include Canada for the securitization and will calculate the premium based on the cumulative CO_2 limits suggested by the Kyoto Protocol. Table 1 summarizes the target reduction basis, CO_2 amounts in 1990, and the permitted CO_2 emissions data for the five countries.

Table 1: Emission reduction targets and GHG emission amounts of the top five countries

unit: Tg CO2 equivalent

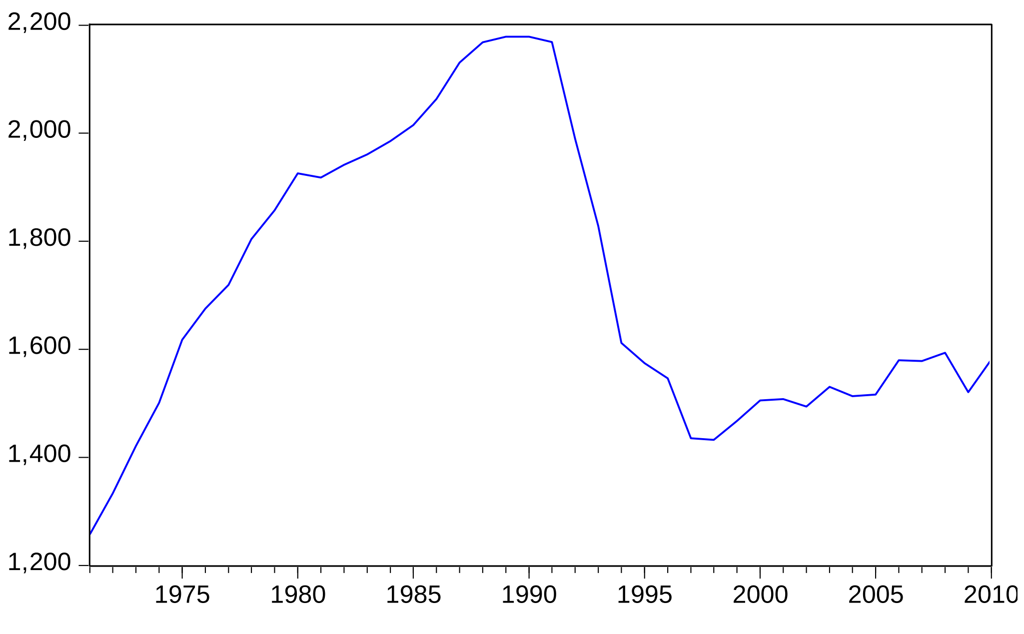
Top 5 countries in Annex 1	Emission reduction target	CO_2 amounts in 1990	Permitted cumulative CO_2 emission amounts during second period	GHG amounts in 1990	Permitted cumulative GHG emission amounts
Russian Federation	0%	2,559.6	20,476.8	3,471.1	27,769.0
Japan	-6%	1071.0	8,053.92	1,258.5	9,463.8
Germany	-8%	1014.2	7,464.5	1,230.3	9,055.0
UK	-8%	591.8	4,355.6	785.0	5,777.4
Canada	-6%	384.5	2,891.4	532.5	4,004.4

Table 2 summarizes the statistics on CO_2 emission increases for the five countries.

Country	Mean	STD	Jarque–Bera	P-value
Canada	5.051282	13.94321	2.245775	0.325339
Germany	-5.5641	28.10613	1.172992	0.556273
Japan	9.853846	38.62117	0.548827	0.760018
Russia	8.305128	72.37046	21.63193	2.01E-05
UK	-3.58974	18.66279	1.874165	0.391769
Russia(1995~)	-1.8875	46.37873	1.360495	0.506492

Table 2 shows that Russia's Jarque–Bera statistics are particularly high. At the end of 1991, after the collapse of the Soviet Union, Russia suffered political instability and inflation until president Putin seized power. Russia's CO_2 emissions, rapidly increasing since 1970, peaked in 1991, then dramatically decreased until they reached 70% of their 1991 level, and then stabilized. Therefore, only post-1995 Russian data should be used. The increase in Russian CO_2 emissions rejects the unit root (ADF: -3.5373) and has a low Jarque–Bera statistic (1.36).

Figure 3: Annual Russian CO_2 emissions amount data[22]



The post-1995 Russian data and the other four countries' time-series data do not reject Jarque-Bera normality, implying that the increases in annual CO_2 emissions are stable and follow a normal distribution. An important component of this study is estimating the cumulative emission amounts from 2013 to 2020. Let S_t be the CO_2 emissions of a country at t year, and $\Delta S_t := S_t - S_{t-1}$ be the increase in CO_2 emissions at t year. Let T_0 be the start year of the second commitment period and $A_{T_0,T} := \sum_{i=0}^{T-T_0} S_{T_0+i}$ be the cumulative CO_2 emissions amount until T year. To calculate the future cumulative CO_2 emissions amount

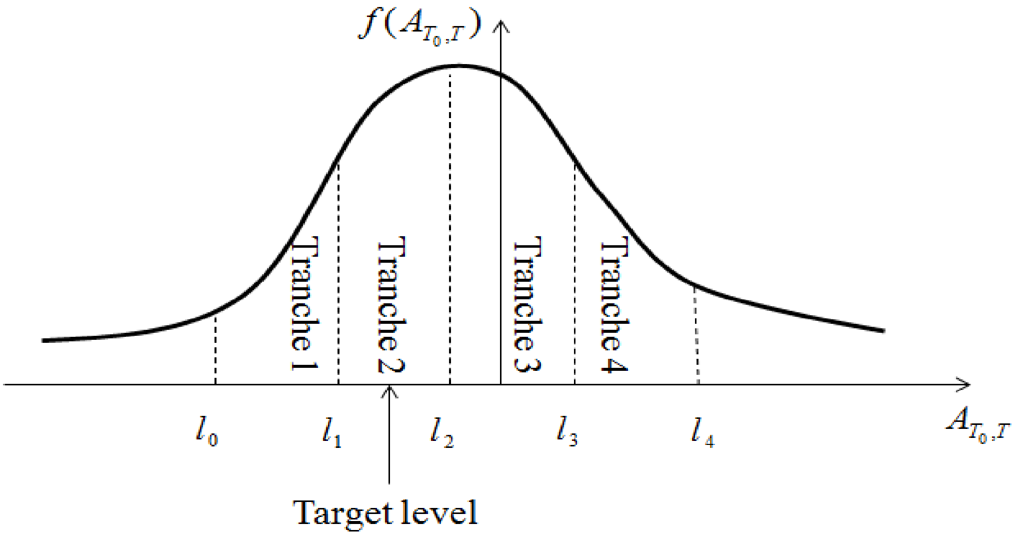
[22] IEA Co2 emissions from fuel combustion 2012
http://www.iea.org/statistics/topics/co2emissions/

$A_{2013,2020}$ based on the Kyoto Protocol, we generate ΔS_t with the given mean and variance in the increase in CO_2 emissions and calculate $S_t = \Delta S_t + S_{t-1}$. Finally, we obtain $A_{T_0,T}$ by integrating S_t's.

5. Designing and Pricing the Securities

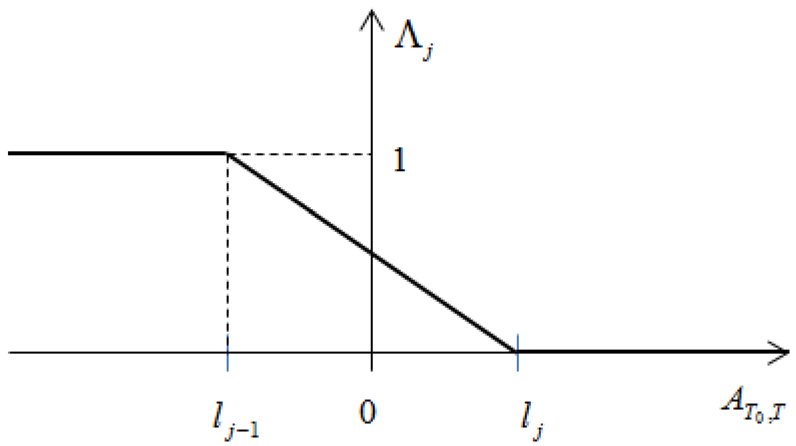
This section prices the security premiums based on cumulative CO_2 emission amounts. We suppose that $A_{T_0,T}$ have bell-shape distribution whose probability density function (pdf) has many frequencies on the medium values and little on either tail. We divide the distribution of $A_{T_0,T}$ into several tranches, by which the coupon of a security belonging to each tranche increases as the frequency of the tranche decreases. Finally, we need to design a security mechanism that will enable a country to belong to a low frequency tranche if it sits below the emissions reduction target level suggested by the Kyoto Protocol. Consider Figure 4 below.

Figure 4: An example of a distribution of $A_{T_0,T}$ and tranches



Let $f(A_{T_0,T})$ be the pdf of $A_{T_0,T}$, and consider the example with three tranches on the distribution of $A_{T_0,T}$. For four real numbers, $l_j, j \in \{0, 1, 2, 3, 4\}$, let tranche j be the interval $[l_{j-1}, l_j), j \in \{1, 2, 3, 4\}$. If $A_{T_0,T}$ belongs to a specific tranche, a security on that tranche should have a payoff decided by the value of $A_{T_0,T}$. To construct the payoff for each tranche j, consider Figure 5 below.

Figure 5: An example of a payoff function on the security



Through simple math, the payoff of tranche j can be decided by

$$\Lambda_j := \frac{[l_j - A_{T_0,T}]_+ - [l_{j-1} - A_{T_0,T}]_+}{l_j - l_{j-1}},$$

where $[a]_+ := \mathrm{Max}\{a, 0\}$, for real number a.

These securities have higher coupons the lower a nation's value for $A_{T_0,T}$ at maturity. Let the annually paid coupon of the security belonging on tranche j be C_j. Assume that the annual coupon C_j has paid constantly until maturity. If one invests an amount of money N_j at the starting time of a security, a constant C_j would be paid annually until maturity, and C_j and N_j will be paid together at maturity. If r is the risk-free interest rate, as the present value of the sum of all cash flows should be equal to the notional value, we have

$$N_j = E_Q\left[\sum_{i=1}^{T-T_0} C_j e^{-ri} | S_t\right] + N_j e^{-rT}, \ t \le T_0 \qquad (1)$$

where t is the most recent year of reported CO_2 emissions data, and generally $t<T_0$. Let s_j be the risk premium of the security. Since C_j should be rational to the national N_j, the payoff function Λ_j, and the risk premium s_j, we can define

$$C_j := \Lambda_j N_j (s_j + r) \qquad (2)$$

Substituting (2) into (1), we have

$$N_j = E_Q\left[\sum_{i=0}^{T-T_0} \Lambda_j N_j (s_j + r) e^{-ri} \,|S_t\right] + N_j e^{-r(T-T_0)}$$

$$= N_j(s_j + r) \sum_{i=0}^{T-T_0} E_Q[\Lambda_j \,|S_t] e^{-ri} + N_j e^{-r(T-T_0)}$$

(3)

Solving (3) with respect to s_j, we have

$$s_j = \frac{1 - e^{-r(T-T_0)}}{E_Q[\Lambda_j|S_t] \sum_{i=1}^{T-T_0} e^{-ri}} - r = \frac{1 - e^{-r}}{E_Q[\Lambda_j|S_t] e^{-r}} - r$$

(4)

Here, since $E[E_Q[\Lambda_j|S_{t+i}]|S_t] = E_Q[\Lambda_j|S_t]$, $i > 0$, the second equation of (4) holds.

6. Numerical Examples

6.1. Based on Expanded Kyoto Protocol

This section generates scenarios, $S_{t-1} \coloneqq S_t + \Delta S_t$, and creates ΔS_t. For ΔS_t, we investigate its historical mean and variance and assume that ΔS_t is distributed normally. Based on this assumption and the reduction plan of Kyoto Protocol, we calculate premium s_j numerically.

We take the UK as an example. Data from the IEA indicate that the UK's 2010 CO_2 emission amount was 483.52 Tg. During the 40 years from 1971 to 2010, the first difference in CO_2 emissions data follows the normal distribution, with a mean of -3.59 Tg and a variance of 18.66 Tg. Since the second reduction commitment period is from 2013 to 2020, the UK's 2013 CO_2 emissions amount, S_{2013}, is the following:

$$S_{2013} = S_{2010} + 3\mu + \sqrt{3}\sigma\varepsilon = 483.52 + 3 * (-3.59) + \sqrt{3} * 18.66 * \varepsilon, \qquad \varepsilon \sim N(0,1)$$

The UK's permitted cumulative CO_2 emissions amount during the second commitment period (assigned amount) is the following:

$$\text{assigned amount} = 1990'\text{s level} * (1 + \alpha) * 8 = 4042.49$$

See Table 1 for the value of α and 1990's level.[23] We set $\{l_0, l_1, l_2, l_3\}$, the boundaries of the tranches, as {α-0.04, α-0.02, α, α+0.02, α+0.04}, and calculate them as

$$l_0 = 1990'\text{s level} * (1 + \alpha - 0.04) * 8 = 3866.73$$
$$l_1 = 1990'\text{s level} * (1 + \alpha - 0.02) * 8 = 3954.61$$
$$l_2 = 1990'\text{s level} * (1 + \alpha) * 8 = 4042.49$$
$$l_3 = 1990'\text{s level} * (1 + \alpha + 0.02) * 8 = 4130.37$$

[23] In this equation, we used the value of the 1990 level (549.2514). This is from the IEA dataset and is slightly different from the value in Table 1 extracted from the Kyoto Protocol. The difference may be caused by the difference in estimating methods between the IEA and the Kyoto Protocol, but it is not significant to this paper. We used only the IEA's data throughout.

$$l_4 = 1990's\ \text{level} * (1 + \alpha + 0.04) * 8 = 4218.25$$

Since we can compute $E_Q[\Lambda_j] = \frac{E_Q[l_j - A_{T_0,T}]_+ - E_Q[l_{j-1} - A_{T_0,T}]_+}{l_j - l_{j-1}}$ from each tranche, we can find the value of (4). The results are as follows:

$\{s_1, s_2, s_3, s_4\} = \{0.00837, 0.00535, 0.00333, 0.00200\}$

Table 3 below shows the CO_2 emission amount distributions of the top five countries in Annex 1 and the risk premiums of the tranches.

Table 3: The risk premiums of the securities underlying the CO_2 emission amount

unit: Tg CO_2 equivalent

Top 5 Annex 1 countries	Emission amounts in 2010	Mean of the increase	Variance of the increase	s_1	s_2	s_3	s_4
Russian	1581.37	-1.89	46.39	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Japan	1143.07	9.85	38.62	7.30110	3.61261	1.87948	1.02566
Germany	761.58	-5.57	28.11	0.00080	0.00039	0.00018	10^{-4}
UK	483.52	-3.59	18.66	0.00837	0.00535	0.00333	0.00200
Canada	536.63	5.05	13.95	>10	>10	>10	>10

The values of the spreads for Japan and Canada are greater than 100%. The Canadian spreads are extremely high; it would thus be inappropriate to issue securities.

Tables 4 and 5 show the results of similar premium calculations using data on the top three GHG emission amounts and the total GHG emission amount,[24] respectively.

Table 4: The risk premiums of the securities underlying the top three GHG emission amounts

unit: Tg CO_2 equivalent

Top 5 Annex 1 countries	Emission amounts in 2010	Mean of the increase	Variance of the increase	s_1	s_2	s_3	s_4
Russian	1540.90	-92.38	161.48	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Japan	1161.28	1.32	34.05	0.61698	0.32920	0.18503	0.10854
Germany	938.67	-13.40	24.62	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
UK	574.95	-9.12	17.27	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Canada	754.54	12.17	100.32	0.44314	0.40278	0.36656	0.33402

Table 5: The risk premiums of the securities underlying the total GHG emission amounts

unit: Tg CO_2 equivalent

[24] http://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3814.php.

Top 5 Annex 1 countries	Emission amounts in 2010	Mean of the increase	Variance of the increase	s_1	s_2	s_3	s_4
Russian	1569.42	-95.08	164.82	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Japan	1208.33	-2.51	39.57	0.05769	0.03667	0.02349	0.01503
Germany	1208.33	-13.07	24.53	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
U. K.	605.40	-8.98	18.07	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Canada	772.83	12.02	100.62	0.42976	0.38935	0.35322	0.32088

The differences among the countries' spread values in the top three and total GHG data seem to be smaller than those in the CO_2 data. However, the values for Canada and Japan are still higher than those of the other countries.

Table 6: The sensitivity of the risk premium of the Canadian securities under ΔS_t and the tranche intervals

The Canadian reduction target, $\alpha = -0.06$

ΔS_t	[-0.11,-0.09]	[-0.09,-0.07]	[-0.07,-0.05]	[-0.05,-0.03]	[-0.03,-0.01]
0	>10	>10	>10	>10	>10
-5	>10	>10	>10	9.35995	4.05191
-10	4.74291	2.43371	1.09289	0.66079	0.34447
-15	0.40183	0.23396	0.13621	0.08488	0.05485
-20	0.06125	0.03842	0.02534	0.01653	0.01048

Table 6 presents scenarios designed to investigate which ΔS_t values and tranche intervals are appropriate for issuing Canadian securities to financial markets. As Table 6 shows, to have a roughly 10% coupon level, the Canadian security should have a [-0.07, -0.05] tranche interval, and Canada should consistently reduce 15 Tg of its CO_2 emissions a year.

However, this calculation methodology is based on the expanded Kyoto Protocol, the emissions standards of which are based on 1990 emission levels. As the political and industrial situation is much different from what it was in 1990, it is not appropriate to apply Kyoto Protocol standards to the security pricing. We thus introduce a more intuitive, simple, and practically applicable construction method for tranche design and risk premium pricing for each tranche in the next subsection.

6.2. Practical Application

Let us consider a way to reduce the expected cumulative GHG emissions amount from 2013 to 2020, $A_{2013,2020}$. For example, we can set

$$\{l_0, l_1, l_2, l_3, l_4\} = \{94\%, 96\%, 975\%, 99\%, 100\% \text{ of } A_{2013,2020}\}.$$

Table 7 presents the results of $s_j, j = 1, 2, 3, 4$, the risk premiums for the new tranches $[l_{j-1}, l_j]$.

Table 7: The risk premiums of the securities based on the practical approach

Top 5 Annex 1 countries		Russian Federation	Japan	Germany	UK	Canada
CO2	$r+s_1$	0.05559	0.07622	0.06242	0.05991	0.10914
	$r+s_2$	0.04190	0.05120	0.04512	0.04395	0.06406
	$r+s_3$	0.03299	0.03669	0.03431	0.03383	0.04127
	$r+s_4$	0.02706	0.02789	0.02736	0.02726	0.02884
3GHG	$r+s_1$	0.03066	0.08552	0.08627	0.07238	0.03346
	$r+s_2$	0.02855	0.05504	0.05534	0.04956	0.03021
	$r+s_3$	0.02685	0.03811	0.03822	0.03606	0.02768
	$r+s_4$	0.02552	0.02820	0.02822	0.02775	0.02574
All GHG	$r+s_1$	0.03061	0.07311	0.09106	0.07351	0.03363
	$r+s_2$	0.02851	0.04987	0.05725	0.05005	0.03031
	$r+s_3$	0.02683	0.03618	0.03891	0.03625	0.02773
	$r+s_4$	0.02551	0.02778	0.02836	0.02780	0.02575

The premium levels in Table 7 seem to be more practical and stable than those in Tables 3, 4, and 5, indicating that the method of setting the tranches proposed in this subsection is more appropriate for designing and pricing the securities.

7. Green Spread: A Clean Environment Indicator

This section uses the proposed method of calculating security premiums to deduce a measure of environmental cleanliness for each country based on their CO_2 emission amounts. One common tranche is assumed in calculating the security spread for each country. The calculated spreads represent increases or decreases in CO_2 emissions in each country and can thus serve as an index of environmental cleanliness in each. Reduced CO_2 emissions reduce the size of the spread and increase the probability of achieving the targeted CO_2 emissions reduction. This spread, the "green spread," can be a financial measure of environmental cleanliness for each country. Suppose the single tranche has upper bound *u* and lower bound *l*. To get the green spread s, we apply these boundaries to the equation (4). Then the formula for the green spread is expressed as

$$s = \frac{1-e^{-r(T-T_0)}}{E_Q[\Lambda|S_t]\sum_{i=1}^{T-T_0} e^{-ri}} - r = \frac{1-e^{-r}}{E_Q[\Lambda|S_t]e^{-r}} - r, \quad (5)$$

where

$$\Lambda := \frac{[u - A_{T_0,T}]_+ - [l - A_{T_0,T}]_+}{u - l}.$$

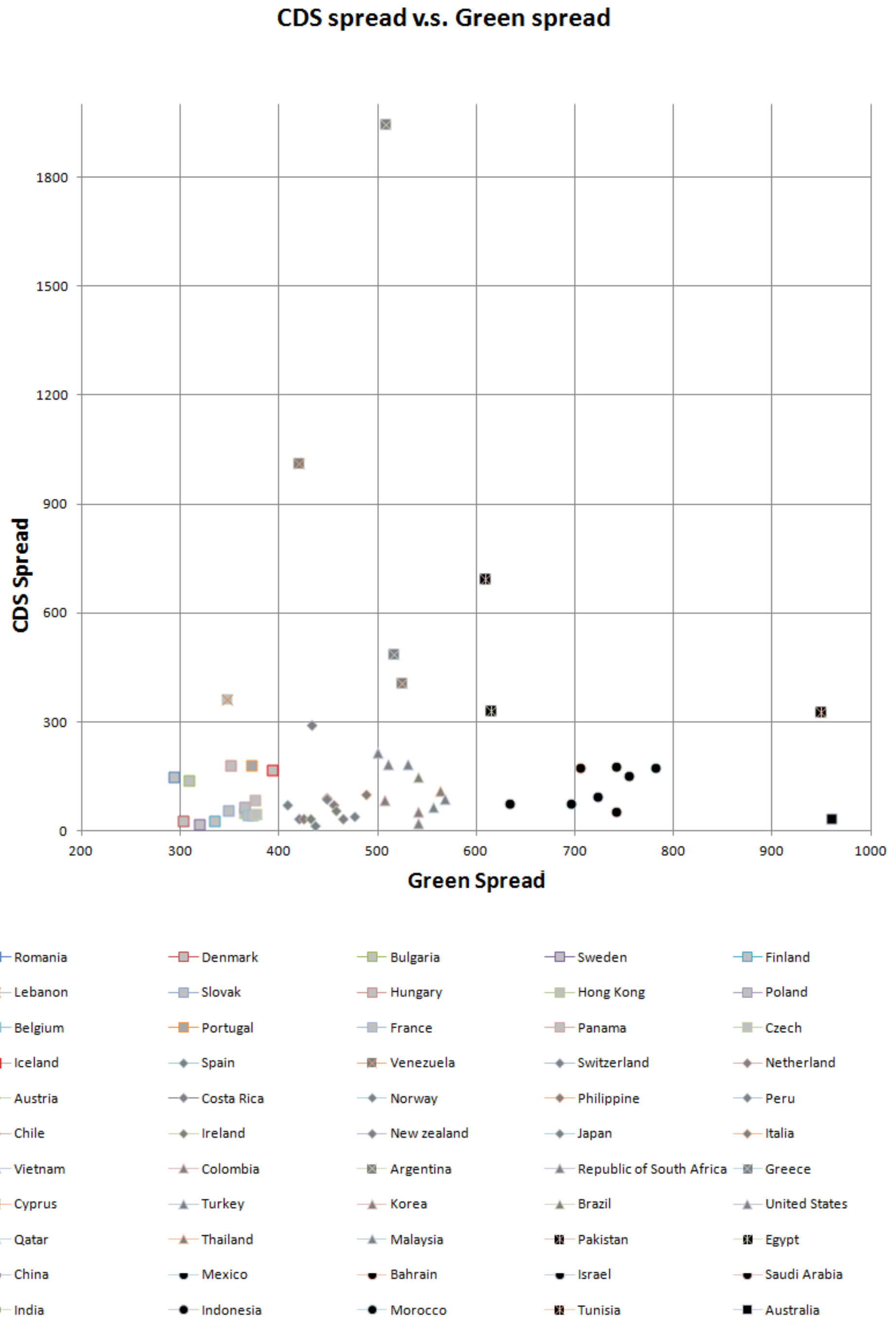
To calculate this spread, we set a tranche limit based on the previously established value of $A_{2013,2020}$, covering *l*=95% and *u*=100% of $A_{2013,2020}$.[25] The single tranche spread is an indicator of cleanliness. It

[25] The first attempt was to set lower and upper tranche limits at 1% and 99% of $A_{2013,2020}$ respectively.

is financially interpreted as follows: if a county emits significant CO_2, the green spread would increase, meaning that the country should pay more to keep its environment clean.

We calculate the green spreads of a few countries and compare them. For reference, we use the CDS spread of each country. The comparative analysis with interpretations of the green and CDS spreads is shown in Figure 7.

Figure 6: The comparison between CDS Spreads and green spreads of countries.



The result was too large to be considered as a spread of interest rates.

Figure 6 exhibits CDS spreads and green spreads of various countries. We categorized countries into three groups based on their green spread; countries with small green spread (below 400 bp), countries with medium green spread (above 400 bp and below 600 bp), and countries with large green spread (above 600 bp). These groups were further broken down into distinct sub-groups based on their CDS spread; one whose CDS spread is below 300 bp and the other whose CDS spread is above 300 bp. Table 8 shows the lists of respective groups that are classified based on their green spread and CDS spread.

Table 8: 6 groups of countries classified by CDS spread and Green spread

Green / CDS	Less than 400bp	400bp to 600bp	Over than 600 bp
Over than 300bp	Lebanon	Venezuela, Argentina, Greece, Cyprus	Pakistan, Egypt, Tunisia
Less than 300bp	Romania, Denmark, Bulgaria, Sweden, Finland, Slovak, Hungary, Hong Kong, Poland, Belgium, Portugal, France, Panama, Czech, Iceland	Spain, Switzerland, Netherland, Austria, Costa Rica, Norway, Philippine, Peru, Chile, Ireland, New Zealand, Japan, Italia, Vietnam, Colombia, Republic of South Africa, Turkey, Korea, Brazil, United States, Qatar, Thailand, Malaysia	China, Mexico, Bahrain, Israel, Saudi Arabia, India, Indonesia, Morocco, Australia

The first group (countries whose green spread is below 400 bp and CDS spread is below 300 bp, the second column of the third row) are the ones with low default ratio and clean environment. On the other hand, the third group on the third row (countries whose green spread is above 600 bp and CDS spread is below 300 bp) bears small credit risk. Yet, pollution seems to be in progress in the countries in this group due to recent economic development. Lebanon, that is the only country in the fourth group, exhibits a high default ratio and a low degree of pollution. Finally, the countries in the last group (countries whose green spread is over 600 bp and CDS spread is over 300 bp) seem to have unstable economies and polluted environments.

The correlation between the cleanliness and credibility of each country seems low, at about 0.07, as seen in Table A1 and Figure A1 in the appendix. Though little correlation between them is evident on the surface, these two variables are influenced by several practical factors, such as level of economic development and national environmental policy. This may imply that studying the correlation between two variables without any control over the relevant factors is meaningless. Therefore, the correlations must be reexamined after controlling for all the factors that could influence the two variables.

Cleanliness and credibility shows significant differences at the 5% level, as seen in Table A2 and Figure A2, when we categorize countries on each continent based on geographical factors. Africa and Oceania show the lowest cleanliness levels, mainly due to deforestation and mineral mining, respectively; Asia, America, and Europe follow. The high number of developing countries in Asia and America cause their low cleanliness levels compared to Europe's. For credibility, North America and Oceania show the highest levels, with USA and Australia representing a huge portion of their continents, due to their low credit risk. South America and Africa show the lowest levels due to their lower stages of development and politic instability. However, the correlations between cleanliness and credibility were neither consistent nor significant once divided by continent.

Table A3 and Figure A3 present the members and non-members of the OECD (Organization for Economic Cooperation and Development). Neither cleanliness nor credibility show significant differences at the 5% level. However, as expected, OECD members with higher levels of economic development and environmental awareness show higher cleanliness and credibility than those of non-members. The correlation between cleanliness and credibility was not significant after separating OECD members from non-members.

Table A4 and Figure A4 present the BRIC (i.e., Brazil, Russia, India, China) group. Rapidly developing BRIC countries show lower cleanliness and higher credibility, which were not significantly different from those of other countries at the 5% level. The differences were not significant, as expected. This result has two causes: the mixture of various cleanliness and credibility factors among BRIC non-members and the insignificant deviations of BRIC values from the average. The correlation between cleanness and credibility was not significant after separating BRIC members from non-members.

Table A5 and Figure A5 consider the PIIGGS (i.e., Portugal, Italy, Ireland, Greece, Great Britain, Spain) group. Their cleanliness and credibility are not significantly different from those of other countries at a 5% level. High cleanliness and low credibility were expected due to their slow growth rates and the impact of the financial crisis. Their cleanliness is somewhat higher than that of non-PIIGGS nations, while their credibility is similar to that of non-members. However, a clear difference is seen between PIIGGS and BRIC nations: the declining PIIGGS show higher cleanliness and lower credibility than the rising BRICs. The correlation between cleanliness and credibility was not significant after separating PIIGGS members from non-members.

Table A6 and Figure A6 show advanced countries (based on IMF criteria) and non-advanced countries. The cleanliness of the advanced countries is not significantly different from that of the other countries at a 5% level, but their credibility is significantly different, also at a 5% level. The advanced countries clearly show higher credibility than the non-advanced countries based on credit risk, but the cleanliness gap between the advanced and non-advanced countries narrows due to the rapid growth of countries such as China. The correlation between cleanliness and credibility was not significant after separating the advanced from the non-advanced countries.

Table A7 and Figure A7 present countries with and without Kyoto targets (Annex I in the Protocol). Countries with targets show a significantly higher level of cleanliness and credibility at a 5% level. The credibility result occurs because many highly developed countries, especially in Europe, have compulsory Kyoto targets. The cleanliness levels of countries with Kyoto targets can be explained by their lower growth rates compared to developing countries and their strong commitment to the Kyoto targets. The correlation between cleanliness and credibility was not significant after separating countries with Kyoto targets from those without.

8. Conclusion

Given the intensity of global climate change, the GHG reductions mandated by the Kyoto Protocol should be implemented faithfully. However, implementation has been difficult because the United States refused to ratify the agreement, and Canada, Japan, and Russia failed to join the second round of carbon cuts. Although the second commitment period was extended by three years, we need to induce as many countries as possible to reduce their GHG emissions by approaching the issue from a new angle.

If the securities linked to national GHG emission amounts designed in this study are issued by UNFCCC or GCF, the investors holding the securities will become participants in GHG emission reduction. For example, if the UK reduces a significant amount of its CO_2 emissions after issuing the securities, investors holding them will have a high probability of making a mint and will therefore request more effective reduction activities of the UK government.

We used the distributions of the increases in CO_2 emissions from 1971 to 2010 for the top five CO_2-emitting Annex 1 countries through data published by the IEA. Evaluating the expected increases in emission from 2013 to 2020, we computed the sum of the CO_2 emissions during the second commitment period and calculated the risk premiums of the securities associated with the tranches whose expected rate would be the same as the risk-free interest rate.

The Russian, Japanese, German, and UK CO_2 emission-backed securities have relatively stable risk premiums or spreads, but the Canadian security is impossible to issue because of its much higher spread value (the sizes of the CO_2 emission amounts between 1990 and 2010 are larger than those of other nations). We identified the Canadian security with a stable coupon spread: Canada should reduce 15 Tg of its CO_2 emissions each year. In addition, we proposed a way of constructing the tranches based on the expected cumulative GHG emission amounts, which are different from those in the Kyoto Protocol, providing more practical and stable risk premiums.

The green spread would act as an indicator of each country's environmental cleanliness. Our analysis using green spreads found no correlation between cleanliness and credibility, even after controlling for geographic, economic, and other factors. Cleanliness should be examined separately, without considering credibility. A higher level of cleanliness is observed in Europe, OECD nations, and countries with Kyoto targets. Africa, Oceania, OECD non-members, and countries without Kyoto targets show lower levels of cleanliness.

We expect that issuing the proposed securities will inspire investor concern about national GHG reduction activities and influence overall public opinion on the issue. Finally, investigating coupon spread calibration methods under risk aversion or reduction duty and developing a methodology for generating CO_2 emitting scenarios for short time spans remain for future research.

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Appendix

Table A1. Pearson correlation with the Green coupon rate and the CDS rate

	Green	CDS
Green	1.00	
CDS	0.07	1.00

Table A2. Green coupon rate by region

	Number	Sum	Mean	Variance
Africa	4	2,857	714	36,905
Asia	15	8,552	570	17,005
Europe	24	9,872	411	9,179
North America	3	1,670	557	17,557
Oceania	2	1,424	712	122,602
South America	7	3,254	465	3,297
Total	**55**	**27,629**	**502**	**23,911**

Table A3. Green coupon rate by OECD membership

	Number	Sum	Mean	Variance
OECD	28	12,878	460	19,706
Non-OECD	27	14,751	546	25,249

Table A4. Green coupon rate of BRIC and non-BRIC

	Number	Sum	Mean	Variance
BRIC	3	1,917	639	10,135
Non-BRIC	52	25,712	494	23,760

Table A5. Green coupon rate of PIIGGS and non-PIIGGS

	Number	Sum	Mean	Variance
PIIGGS	5	2,243	449	3,410
Non-PIIGGS	50	25,386	508	25,749

Table A6. Green coupon rate of advanced countries and non-advanced countries

	Number	Sum	Mean	Variance
Advanced	26	12,002	462	19,752
Non-Advanced	29	15,626	539	25,560

Table A7. Green coupon rate of Annex I parties of Kyoto protocol and non-Annex I countries

	Number	Sum	Mean	Variance
Annex I	27	11,590	429	16,514
Non-Annex I	28	16,039	573	21,427

Figure A1. Main countries

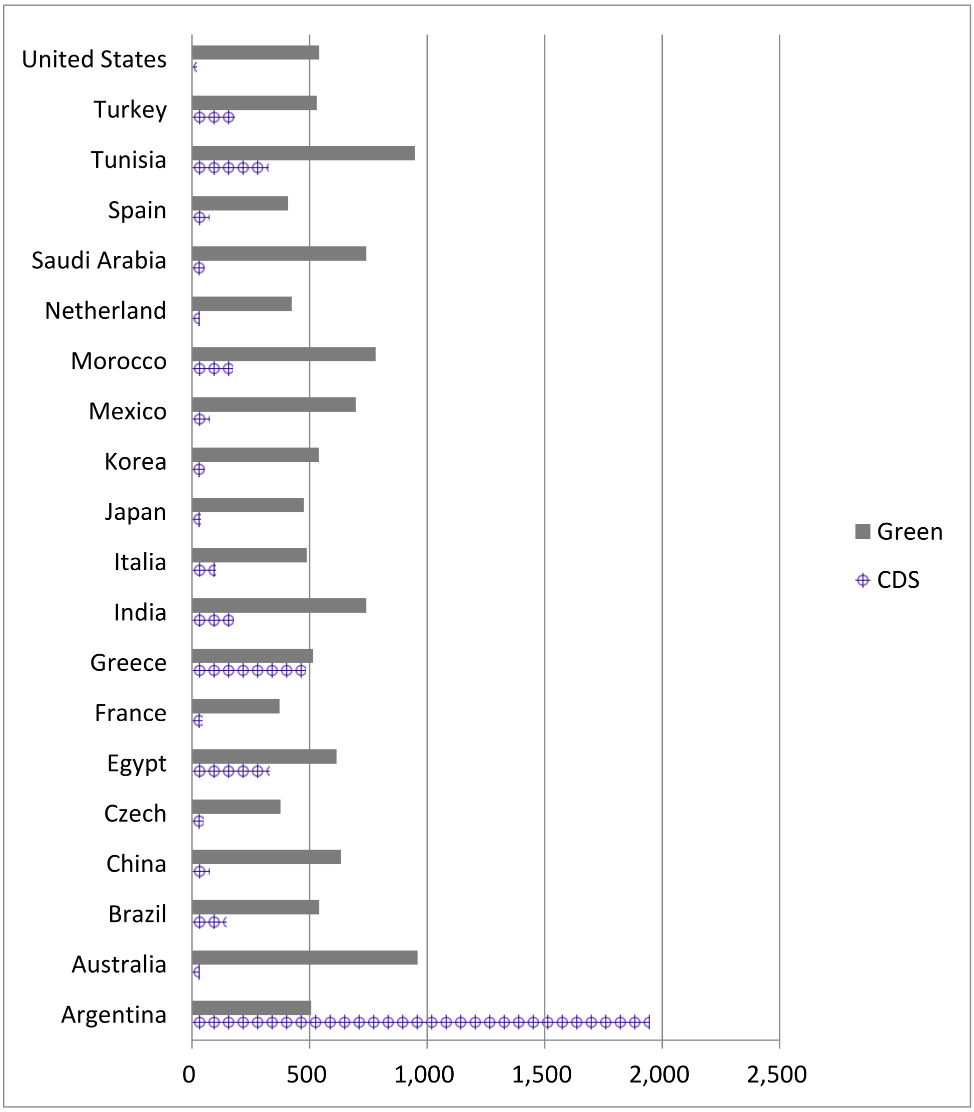

Figure A2. By region

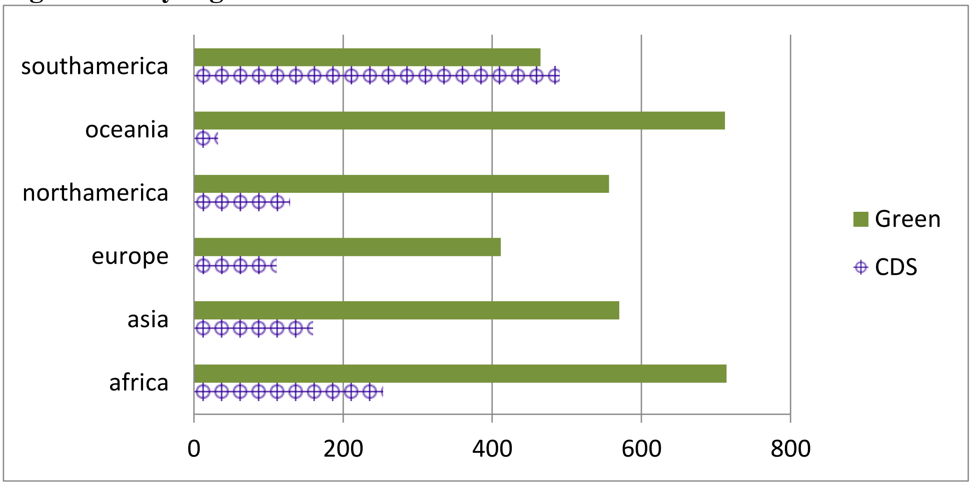

Figure A3. OECD vs. non-OECD

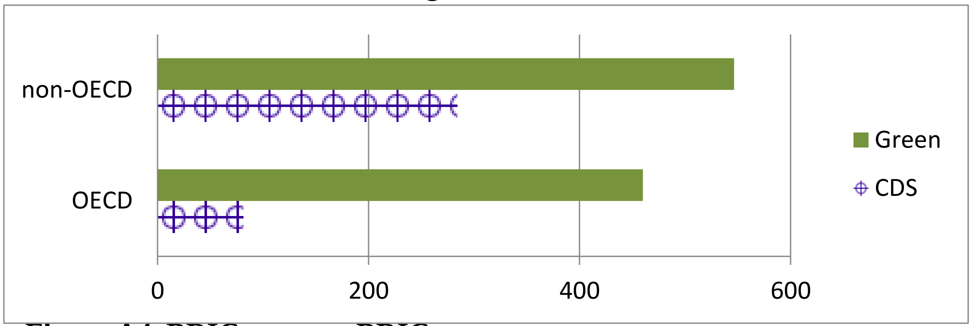

Figure A4. BRICs vs. non-BRICs

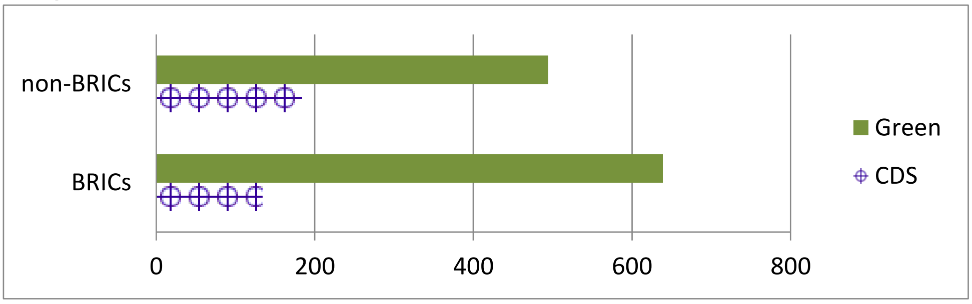

Figure A5. PIIGGS vs. non-PIIGGS

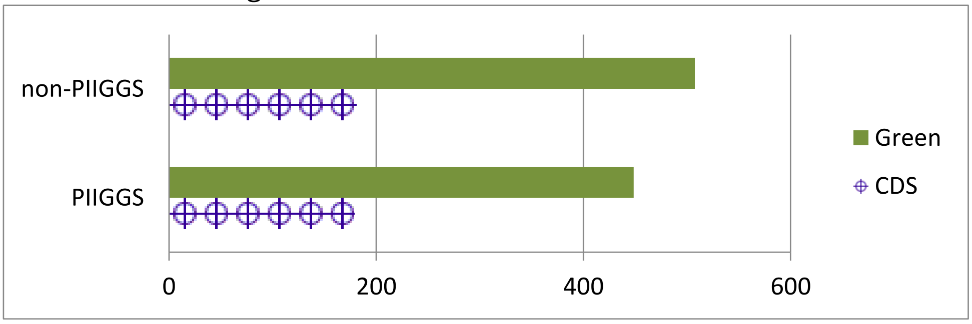

Figure A6. Advanced vs. non-advanced

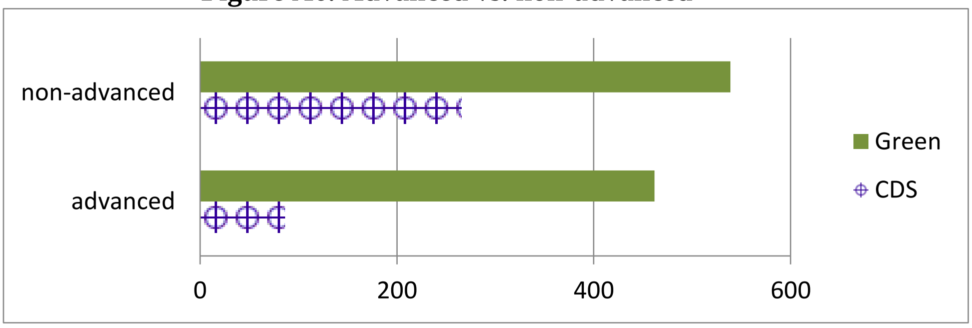

Figure A7. Annex I parties of Kyoto protocol vs non-Annex I countries