A Review of Carbon Studies

LI Larry
XUE Jinjun

Climate warming has received much attention in recent years, and the literature in this area has grown rapidly. Economists normally investigate the causes and solutions of carbon emission, while researchers in finance discipline pay more attention to the effect of environmental policies on firms' performance and the market performance of carbon emission related securities. This paper provides a comprehensive review from both theoretical and empirical perspectives. Overall, the understanding of the key driving forces of carbon emission reduction, corporate performance and trading strategies of carbon emission related securities remains largely inconclusive, and the inconsistency in empirical findings are primarily due to methodological problems, such as model design, choice of variables and data availability. On the basis of existing literature, we make recommendations for future research direction.

Keywords: Carbon Emission, Climate Change, Carbon Finance, Carbon Market

Ⅰ. Introduction

It is widely recognised that the planet is warming up, and it is getting warmer every year. Therefore, the climate risk is an increasing concern for everyone in this planet. The strong economy growth before the global financial crisis has been one of the major driving forces affecting the surge in energy consumption and greenhouse gas (GHG) emissions. The consequence of the climate change could be irreversible and costly. For example, the climate warming could lead to natural disasters, such as typhoon, hurricane, droughts, and flood. These extreme events are like to increase in both frequency and magnitude. In addition, the climate warming is causing the decline in the many types of vegetation, which are crucial to food security and livelihoods (Dion, 2015). Climate change can cause the decline in the number of vertebrate species, which has been reduced by half in the last four decades. Living environment of animals, such as polar bears, seals, and walruses has been seriously deteriorated. The 2009 Copenhagen International Climate Conference has acknowledged that reduction in GHG emission is needed to control the global temperature between 2 degrees Celsius (3.6 degrees Farenheit). This is a challenging task, and fails to act could lead to unaffordable consequences.

Fortunately we have observed that big GHG emitters, such as European Union, China and United States, have expressed deep concerns on this issue. For example, EU has committed to reduce its GHG emission by 40% below 1990 levels by 2030. China promised that its emission will reach the peak by 2030. US president Barack Obama said that US emission will be cut by 26%-28% by 2025 from 2005 level. However, the reduction target can only be achieved if all countries would fulfil their climate commitments, including all developing and developed countries, which is problematic in reality. We still heard different voices on climate management plan including few developed countries, such as Canada and US (Dion, 2015).

The climate warming has received much

attention from government officials and academics, and how to smoothly transfer the current economic development model to a low carbon economic model with desirable economic growth is a challenging issue for everyone, for developing countries in particular. The new climate economy report (2014) points out that "*In developing countries, an important concern is that attempts to tackle climate change will derail their immediate and overriding objective of rapid economic growth and poverty reduction, and the challenge facing developed countries is to modernise public finance, enhance innovation and boost growth and employment in ways that accelerate progress on decarbonisation*". For example, Vietnam has increased the tax burden on firms from polluting industry, while China has promised to invest more aggressively in strategic high-tech, low-carbon industries in the future. EU has established the largest carbon trading markets, and implemented cross board tax on polluting products from countries without solid environmental protection regulations. However, the deification of the low-carbon economy varies from country to country. Consequently, national environment policies also differ from country to country largely depending on their individual context. Xue (2014) concludes that even the importance of low-carbon economy has been widely recognised, unfortunately very few theoretical analysis of this concept has been conducted and even the definition, the target of analysis and the methodology remain far from conclusive.

Research in this area has mainly focused on two anomalies: the causes and solutions of climate warming (green house emission in particular) and effect of environmental standards on corporate performance and financial markets. However, the literature is varied and inconsistent. Empirical studies employ different methodologies, use a wide variety of samples spanning a number of time periods and ask different questions when examining how the carbon emission affects the economic or financial performance at country, region and firm level. A comprehensive review of studies in this area is required, and this study will meet the challenge and also provide the directions for future research.

This paper reviews the literature on carbon studies from both theoretical and empirical perspectives, and identifies the key factors of the inconsistency in the literature. Much attention has been given to the studies in economic and finance areas due to the inconclusive research findings. This paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the mathematical measure for carbon emission estimation using factor analysis methodology, and Section 4 summarizes the main findings of the study and outlines possible research directions for the future.

Ⅱ. Literature Review

1. Literature from the Economic Perspective

Issues related to carbon emission and reductions have been well documented. Stephane Dion, the Canadian Environment Minster, argues that each country needs to make a commitment to introduce constructive policies to lower their emissions, adapt to climate change impact, and create carbon sinks while maintaining desirable economic performance. Realistically, it is a challenging task, which requires the joint effort from all countries. Traditionally, carbon emission research has primarily focused on the interrelationships among regional environmental responsibility (Marques et al., 2012 &2013; Zhang, 2015), carbon-intensive industries (Kwon, 2005; Andreoni and Galmarini, 2012; Yabe, 2004; Suh, 2006; Butnar and Liop, 2011), taxation (Carraro et al., 2012; Dong et al., 2015), regional economic development (Davis et al., 2003; Lise, 2006; Wang et al., 2015) and supply chain (Sundarakani et al., 2010; Meng et al., 2013).

Xue (2014) provides a more comprehensive review of this area and defines a low-carbon economy should have low-carbon features in at least eight different aspects, including production, energy, technology, transportation, consumption and life style, housing and building, farming and city.

(1) Carbon Emission and Macroeconomic Factors

Numerous attempts have been made to explain the regional environment responsibility for carbon emission. The environmental responsibility can be further categorised into seven sub-principles, namely production, consumption, income, income-weighted, consumption-weighted, comprehensive, and weighted comprehensive principles (Zhang, 2013). The production principle is the most widely used principle in environmental responsibility studies. Based on this principle, the carbon emission is directly caused by the production activities (Gallego and Lenzen, 2005). However, this principle fails to identify the carbon leakage arising from the international and inter-regional trade. Consumption principles, on the other hand, fill the gap by arguing that consumers need to bear their responsibility caused by their consumption (Munksgaard and Pedersen, 2001; Peter and Hertwich, 2008). Income principle further assigns the environmental responsibility for emission to all input providers, such as workers, investors, governments and foreign exporters, as their income is generated during the process of carbon emission, and arguably income principle can be used to minimize the carbon linkage (Zhang, 2010; Marques et al., 2012&2013). Production, income and consumption principles are treated as the basic principles for allocating environmental responsibly. Based on these three principles, income-weighted, consumption-weighted, comprehensive, and weighted comprehensive principles are introduced. The overall implication of these principles is that both the producer and consumer should share the environmental responsibility of the product. However, Zhang (2015) studies the provincial responsibility for carbon emission and provincial carbon multipliers in China by using a multi-regional input - output model, and finds that change in principle might cause significant variations in the responsibility of carbon emission for provinces.

Most empirical research mainly focuses on the carbon emission of carbon-intensive industries, such as transportation, power, and energy. Andreoni and Galmarini (2012) investigate the key factors influencing the European CO_2 emissions variation of water and aviation transport activities for the period 2001-2008, and they find that the economic growth is the major contributor to the CO_2 emissions increases in water and aviation industry of all 27 EU states. On the contrary, the energy efficiency improvements largely contributed to the emission reduction. Gonzalez and Martinez (2012) examine the influential factors on sixteen industrial sectors emission in Mexico for the period 1965-2003. The empirical results confirm that Iron and steel, cement, chemical, petrochemical, and mining emitted 58.6% of the total CO_2 emissions during the sample period. Additionally, they further point out that external economic events, such as privatisation, Mexican oil boom, economic crises, and variation in oil prices have contributed to increase the effect in the total carbon emission. Based on data drawn from Chinese food industry during the period 1986-2000, Lin and Lei (2015) report that the energy intensity and industrial activity are the most important factors affecting reduction and growth of carbon emissions for food industry in China. The empirical findings further suggest that improving energy efficiency, optimizing industrial scale, and restructuring energy usage are effective approaches for reducing carbon emission. Similar studies can be found in householder sector (Wier, 1998), service sector (Suh, 2006), and manufacturing sector (Jeswiet and Kara, 2008).

The linkage between carbon emission and supply chain is another well documented area. Research in this area pay more attention to the spill over of CO_2 emission, and a region or country's position and participation level in domestic and international supply chains through trading activities. Davis et al. (2011) claim that 10.2 billion tons CO_2 or 37% of global emission are from fossil fuels traded internationally and an additional 6.4 billion tons CO_2 or 23% of global emissions are embodied in traded goods. A green supply chain management (GSCM) approach is requested to improve the environmental performance and reduce the environmental burdens of supply chains (Sarkis, 2003; Zhu and Sarkis, 2004). Up to date, most of GSCM studies have either been descriptive frameworks or conceptual models due to the difficulty of data collection (Flapper et al., 2005; Seuring, 2013). Fahimnia et al. (2013) conduct a case study of an Australian company by evaluating the forward and reverse supply chain influences on the company's carbon footprint. They find that the results of optimal supply chain cost analysis highly depend on the variations in carbon price. Meng et al. (2013) document the relationship between China's inter-regional spill over of CO_2 emissions and domestic supply chains for the period 2002 and 2007. Results of this study show that a region's CO_2 emissions depend on its intra-regional production technology, energy usage efficiency, as well as its position and participation degree in domestic and global supply chains. The embodied CO_2 emission of all regions has been increased significantly due to the deeply involvement in either domestic or global supply chains. However, the good news is that the energy-use elasticity of CO_2 emission at the national level changes very little during the sample period mainly due to the improvement of energy-use efficiency.

Liu et al. (2015) further distinguishes the carbon emission embodied in commodities for domestic final consumption and these for export by using Chinese data respectively for the period 1997-2007. They find that the carbon emission embodied in domestic consumption and export has significantly increased during 1997-2007 due to the robust domestic economic development and China's increasing participation in the global trade. However, CO_2 emission performance varied significantly across regions. For example, inland territory, such as Northwest part of China, is associated with the lower energy efficiency and highest energy consumption per unit of output. In contrast, developed regions tend to have a better industrial structure and higher energy-use technology, suggesting that technology is the key of carbon emission reduction. Zhang et al. (2014) take a further closer look by dividing 1997-2007 into two sub-periods (1997-2002 and 2002-2007), and draw the similar conclusions.

In recent years, how to balance international economic competiveness and carbon leakage has become one of the major concerns in domestic discussions in many developed countries. One of the popular solutions is carbon tariff which is levied on commodities exported from developing countries without comparable actions in carbon emission reduction (Wu and Tang, 2014). Consequently, major emitting developing countries, such as China and India, will be under great pressure for emission reduction. However, the definition of comparable action is yet to be clearly specified (European Commission, 2009). Dong et al. (2015) investigate the economic and environmental effects of carbon tariffs on Chinese export by considering three policy scenarios. The empirical findings illustrate that the competitiveness of China's energy-intensive and trade-exposed industries will be deteriorated if export tariffs are imposed. However, the imposed tax cannot significantly reduce Chinese domestic CO_2 emission due to lack of direct abating incentive for energy inputs. Carraro et al. (2012) explore the relationship between carbon emission reduction and taxation from a different angle. They evaluate the financial cost of a transition towards a green, low carbon economy induced by the carbon tax revenue based on four global tax scenarios. The empirical evidence shows that the in all tax scenarios investment increase in energy-related research and development, and decrease in oil upstream. The global carbon tax revenue will be very high in absolute terms and behave like a "carbon Laffer' curve, first increasing and then decreasing with the level of taxation.

(2) Carbon Emission and Country-Specific Factors

Researchers have also showed the increasing interests in the driving factors of carbon emissions at the country level. Davis et al. (2003) find that warm weather, energy consumption structure and technology innovation are the key contributors to the carbon emission in US for the period 1996-2000. Lise (2006) concludes that the rapid economic growth was the major contributor to the carbon emission increase in Turkey between 1980-2003. Similarly, Hatzigeorgiou et al. (2008) state that the income effect was the dominating driving factor in the carbon emission increase in Greece. Wang et al. (2015) investigate the key driving forces of carbon emission in China by using production theoretical decomposition analysis. The empirical findings show that economic development is the largest contributor to the carbon emission, followed by the energy structure and low energy efficiency. In addition, CO_2 emission and driving factors varied significantly across east, central and west China. Recently, Lin and Du (2015) investigate the dynamic of carbon emission performance in china for the period 2000-2010. They find that the overall carbon emission performance in China improved by 4.1% during the sample period mainly due to the improvement of efficiency. However, carbon emission performance varies among different regions which is consistent with Liu et al (2015)'s findings. For example, the east and central areas of China were the leading regions of improvement, and the west areas experienced deterioration in carbon emission performance. Again, technology progress is the main issue. More effective environmental policies and investment should be further strengthened to make the change. Lewis (2010) reports that the development of renewable energy investment in China up to date is impressive, but it still not sufficient enough compared to the reduction target.

In recent years, several studies were conducted to compare the carbon emission trends across countries. Zhang et al. (2012) empirically investigate the impact of nine CO_2 factors on the carbon emission in 20 developing countries with data from 1995 to 2005, and they conclude that the economic growth is the most important contributor to CO_2 emission increase. In contrast, the technology improvement is the most important component to CO_2 emission reduction. Kim and Kim (2012) employ data from 26 OECD countries and 17 non-OECD countries for the period 1990 to 2006, and examine the relationship between the world-wide CO_2 emission trend and six key contribution factors. Again, they find that economic development has been the dominant contributor to the growth of CO2 emissions in all countries while changes in potential energy intensity and energy mix have led to emission reduction in almost all OECD and non-OECD countries. Saveyn et al. (2012) conduct a comparative study by examining the impact of different GHG emission mitigation policies on the economic performance in China, India, and Japan respectively. Three scenarios with different projected carbon prices are used to explore the economic outcomes in these three countries, and the fourth scenario is based on the 2 degrees Celsius target, reducing the global GHG emission by 50% in 2050 relatively to 2005 level.

All four scenarios assume a single carbon price for the world. They conclude that improvement in energy efficiency, deployment of carbon power, and introduction of carbon trade will be essential for achieving the 2 degrees Celsius target in 2050. In addition, authors argue that postponing significant emission reduction may not accrue an economic benefit over time whereas it may increase some risks by possibly overstretching the reliance on zero-carbon technologies.

It is also worth noting that China has been consistently under the spotlight of carbon economic and performance studies, because China has become the largest emitter in the world since 2007, and accounted for 24.6% CO_2 emission of the world's total emission in 2010 (Lin and Du, 2015). Consequently, how to balance the economic development and carbon emission reduction has become a vital challenge for the Chinese government. Thus, numerous attempts have been made to investigate the static and dynamic CO_2 emission performance in China. Researchers employ different methodologies, use different sample data spanning a number of time periods and ask different questions when examining how the carbon emission affects the economic performance of China, and how to reduce the carbon emission in a more effective way in China (Wang et al., 2010; Zhou et al., 2010; Guo et al., 2011; Choi et al., 2012; Meng et al., 2013; Xue, 2014; Liu, et al., 2015; Li, et al., 2015).

The empirical results of these Chinese studies have many policy implications, including (1) further investment in environment related research and development is required to enhance the energy usage efficiency, in the west part of China in particular; (2) how to balance the carbon responsibility and regional economic development is a big task for the Chinese government, because energy rich regions normal are located in inland area with relatively lower per capital GNP. Therefore, regional income level needs to be considered while setting carbon reduction target; (3) government should play an important role in pricing of energy, taxation, and influencing people's consumption and production behaviour.

Literature shows that empirical researchers are tempted to try various combinations of the explanatory variables and report the ones they like, typically the ones that produce "good" results and/or confirm pre-conceived beliefs. Unfortunately, the area of climate change research is not exceptional. Michaels (2008) concludes that there is substantial evidence of selective reporting by examining 166 papers in climate change area published by Science and Nature. His argument is further confirmed by Swanson (2013) and Maclean and Wilson (2011). Havranek et al. (2015) investigate the selective reporting issue in the literature on the social cost of carbon (SCC) estimation by using a meta-analysis approach, and find that some authors of previous studies prefer to report SCC estimates for which the 95% confidence interval, which creates an upward bias in the literature. In contrast, some small SCC estimates without statistical significance are more like to be omitted from reporting, which is consistent with the literature. Therefore, finding an appropriate research methodology remains a challenging task in the future.

In short, the development of a low carbon economy is a long lasting and complex task, and how to balance economic growth and carbon reduction has become an inevitable challenge confronting all countries in this world. Literature shows that there are many factors influencing the carbon emission at national, industrial, regional, and city levels. However, we can safely conclude that technological progress will play an essential role in reducing carbon emission in the future. In addition, the carbon emission reduction is not a mission for any particular country. Therefore, international collaboration among all countries will be critical. Otherwise reduction target cannot be achieved.

2. Literature from Finance Perspective

Climate change research in finance area has been conducted in two major areas: (1) investigate the effect of environmental standards on corporate performance as measured by stock returns or accounting performance; (2) examine the market performance of carbon emission related financial securities. However, so far we have not found a conclusive answer on whether environmental regulation creates or destroys valuation. Opponents of regulation argue that environmental regulations add the extra cost on production, which deteriorates the corporate financial performance because business cost is lower for firms to operate in countries with loose environmental regulations (Gray and Shadbegian, 1995). On the other hand, proponents claim that environmental regulations create value instead of destroy value because the cost saving associated with low environmental standard could be exaggerated and eventually it might be more costly if firms choose not to comply with high environmental standards (Dowell et al., 2000). Therefore, it is safe to claim that the empirical relationship between corporate environmental standards and firm value is far from conclusive.

(1) Environmental Policies and Firm Performance

Hamilton (1995) and Hart and Ahuja (1996) argue that firms with higher environmental management standards outperform compared to firms with poor environment practices, because investors expect that the eventually cost of environmental clean-up for polluting firms is much higher than the cost for firms with better environmental records (Dowell et al., 2000). For example, in 2010 an undersea BP oil well exploded in the Gulf of Mexico 40 miles off the Louisiana coastline. Millions of gallons oil spewed from the ocean floor 5,000 ft beneath the ocean surface and caused one of the worst environmental disasters in US history. The company mounted a massive clean-up operation (the total cost after five years now stands at $28 billion) and has agreed to pay $18.7 billion in 2015 to settle all federal and state claims arising from the 2010 oil spill (WSJ, 2015). Recently, Volkswagen Auto Group faces penalties up to $18 billion issued by U.S. Environmental Protection Agency for designing software for diesel cars that deceives regulators measuring toxic emissions (Reuters, 2015). Meanwhile, Shares of Volkswagen have plunged nearly 50% since the news of the automaker's Clean Air Act violations first surfaced in September 2015. The total cost of this scandal for VW could be up to $87 Billion in total, including cost of recall and repair, and fines (Agnihotir, 2015). Therefore, recognition of environmental performance does have a positive impact on firm value.

Ramiah et al. (2013) investigate the effect of green policy announcements on the Australian stock market over the period 2005-2014 by using event study methodology, and ask whether these announcements are value constructive or destructive for equity investors. The empirical findings their study are mixed. On one hand, there are 21 out of 35 industries affected by the announcements of green policies. On the other hand, the announcements of green policies had not impact on the average stock performance of other 14 industries. Additionally, out of the 21 industries, sectors experiencing negative, positive and mixed abnormal returns are 10, 7 and 4 respectively. Therefore, further research needs to be conducted to investigate the relationship between Industrial-specific characteristics, stock returns and green policy announcements.

(2) Carbon Trading Market and Carbon EmissionRelated Financial Securities StudiesI

1) The Development of European Union's Emissions Trading Scheme (EU-ETS)

In 2005, the European Union (EU) lunched a large-scale GHG emissions trading program - European Union's Emissions Trading Scheme (EU-ETS), which is considered as one of the major milestones of climate policy. The EU-ETS was the first and is to date the largest international system for trading GHG emission allowance, covering installations across all 25 EU member states. The implementation of EU-ETS has been divided up into three distinct trading periods over time, known as phases. The first phase of the EU ETS covers the period 2005 to 2007 and could be regarded as the pilot phase. The second phase of the EU ETS ran from 2008 to 2012, the same period as the first commitment period under the Kyoto Protocol, which requires all EU member states to cut their emission by 8% compared with their 1990 level. The third phase of the EU ETS runs from 2013 to 2020, and it is expected that the EU GHG emission will be reduced by 21%, relative to 2005 level. (EU ETS Handbook, 2013).

The EU Emissions Trading System (EU ETS) is a 'cap and trade' system, in which the quantity of emission of larger polluters in EU is capped by the European commission. The emission cap is gradually reduced annually to meet the predetermined target under the Kyoto Protocol. Polluters are allocated emission allowances, either free or via auction, which they surrender annually against their assessed emissions. Companies with excess allowances can sell their surplus allowances via the EU ETS for extra profit, and companies also can buy extra allowances if their actual emission exceeds the cap. This market mechanism provides the motivation for polluter to minimize their GHG emission. Typical allowances can be traded in the EU ETS are European Union Allowances (EUAs), Certified Emission Reductions (CERs), and Emission Reduction Units (ERUs). There is a restriction that unused emission allowances cannot be banked at the end of each phase, implying the market value of these emission allowances will become zero at the end of each phase. Major participants of EU ETS market are companies in polluting industries and an emerging class of so called "Carbon Investors". Fusaro (2007) reports that there are funds available specialised in carbon asset trading.

2) Carbon Emission Related Financial Securities Studies

The grand opening of EU ETS has provided a great opportunity for researchers to investigate the effect of EU ETS on stock returns, investment strategy and risk management. The cost of EUAs, CERs and ERUs has significant impact on the prices of power, gas and other emission related commodities and eventually the overall economic activities. The empirical studies of carbon market have concentrated on the EU ETS markets because it is the largest, most liquid and most developed, accounting for approximately 98% of global transactions in 2007 (Daskalakis et al., 2009). There are several different research lines focus on the different aspects of EU ETS. The first line of research focus on the analysis of spot market performance of emission allowances and how to find a valid CO_2 spot price model to value potential derivatives (Paolella and Taschini, 2008; Benz and Truck, 2009; 2008; Seifert et al., 2008). The findings suggest that model selection should be based on the adequacy of capturing characteristics like skewness, excess kurtosis and in particular different phases of volatility behaviour in the returns. The second line of research examines the effect of price movement of carbon allowances on the stock returns of firms in Europe, electrical power companies in particular. Overall findings show that there is a positive relationship between the price of carbon allowances and stock returns in the European power sector (Oberndorfer, 2009; Veith et al. 2009; Koch and Bassen, 2013). The third line of research investigates the impact of the carbon price crash in April 2006 on the market performance of carbon intensive firms by using event study methodology. The empirical evidence shows that change in carbon regulation plays an essential role in determining the performance of polluting firms (Bushnell et al., 2013; Jong et al., 2014). The fourth line of research is about the technology underlying the coal and gas generated power. Sijm et al. (2006) and Smale et al. (2006) find that power companies tend to be much more profitable via increasing electricity price due to the introduction of the EU ETS.

Oestreich and Tsiakas (2015) empirically investigate the effect of the European Union's Emission Trading Scheme on German market for the period 2003-2012, and identify that firms (normally polluters) received free carbon emission allowances outperformed significantly compared to firms did not for the period November 2003- March 2009 due to the presence of "carbon premium". The carbon premium exists because free allocated carbon allowances constitute an opportunity cost to polluting firms. Those firms would like to increase their profit margin by increasing output prices, reducing production, or switching to more carbon effective technologies. The unused carbon allowances can be traded in the market for extra profit. Therefore, free allocation of carbon allowances can increase firms' profitability (Goulder et al., 2010). However, Oestreich and Tsiakas (2015) find that the carbon premium disappeared for the period April 2009-December 2012 because of the passing of an EU law in April 2009 specifying that allowances will be mainly sold in auctions beginning in 2013. In short, polluters outperform clean firm when free carbon allowances are available. However, the performance premium vanishes once the market knew with certainty that the free lunch is over for polluters.

Mizrach and Otsubo (2014) analyse the market liquidity of European Climate Exchange (ECX) by using tick data for the period 2005-2013. The findings imply that ECX is a highly liquid and dynamic market, implying that ECX is associated with high trading volume growth rate and narrow bid and ask spread. In addition, the level of co-integration between future and spot market is very high. Empirical findings indicate that the ECX future market is providing between 75%-88% and 64%-72% of price discovery for EUA and CER trading respectively, which is consistent with the literature that the more liquid market should lead price discovery (Figuerola-Ferretti and Gonzalo, 2010). They propose a simple trading strategy that enters at the close on trading days with large imbalances, and profit the investment on the following trading day.

Schultz and Swieringa (2014) investigate the catalysts for price discovery of fungible securities in the EU ETS by using high frequency data for the period 2009-2011. They examine the effect of trading cost, leverage, and market segmentation on the short and long term process of price discovery in the second phase of EU ETS. As we know that EUAs and CERs can be traded at 9 different exchanges and they are essentially similar with one another. Therefore, it is assumed that market prices of two perfectly substitutable securities should change simultaneously when new information arrive if the market is efficient, otherwise investors may have preferences for particular securities. However, empirical evidence does not support this argument. Empirical evidence of this study shows that securities with lower trading cost exhibit faster adjustment to newly arrived information because investors want to maximise their profit margin by trading the one with the lowest trading cost if several securities are identical in other characteristics. In contrast, leverage and market segmentation are not important driving forces of EUA and CER price recovery in the EU ETS.

In general, the literature on carbon futures is thin mainly due to the short trading history and inconclusive research methods. The limited empirical evidence shows that pricing carbon future is challenging task because the EU ETS is divided into several distinct phases (EU ETS Handbook, 2013). Benz and Hengelbrock (2008) arguably is the first study empirically investing the liquidity and price discovery of two EUA future markets, ECX and Nord Pool for the phase 1 2005-2007. They find that the market liquilitidy has significantly increase and the bid-ask spread has narrowed during the sample period. Rittler (2012) investigate the relationship between EUAs future and spot markets, and find that there is a close relationship between the volatility dynamics of both markets. In addition, there is a spillover from the futures to the spot market, indicating that the futures market incorporates information first and then transfers the information to the spot market. Conard et al. (2012) examine the effects of EU policy announcements on the market performance of EUAs, and they find that these policy announcements do have a strong and immediate impact on EUA prices. On the other hand, they fail to find a strong connection between EUA prices and macroeconomics indicators, such as the future economic development as well as the current economic activity.

As mentioned above, unused emission allowances cannot be roll overed to the next distinct phase. Consequently, market participants' investment strategies have been greatly influenced. Daskalakis et al. (2009) find that the prohibition of emission allowances banking between distinct phases of the EU ETS has significant impact on the pricing of emission allowances and the associated derivative assets. Thus, the movement of EUA price is associated with high volatility and the existence of extreme discontinuous variations. Additionally, the emission allowance spot prices are likely to be characterised by jumps and non-stationarity. In the case of future market, the movements of intra phase and inter phase future contracts behave differently because investors are more likely to hold a short future position to minimise the uncertainty related to the allowance allocation and risk of failing compliance. Finally authors suggest that the prohibition of banking carbon allowances needs to be abolished because the trading obstacles inhibit the market liquidity, and increase the market uncertainty, which is not consistent with the primary objective of the EU ETS market.

Ⅲ. Research Methodologies

1. The Kaya Identity

Quantitative analysis on climate change and its mitigation began when climate change problems caught the attention of scientists. Climate change is a multidisciplinary topic covering economic development, finance, supply chain, econometrics, trade and technology development. Therefore, it is not a surprise that the research methodologies in carbon research are highly inconclusive. The Kaya Identity can be treated as one of milestones in the development of carbon emission evaluation (Kaya and Yokoburi, 1997). The Kaya Identity argues that total emission level can be expressed as the product of four inputs: population, GDP per capita, energy use per unit of GDP, carbon emissions per unit of energy consumed. The specification of the Kaya Identity is summarised in the following form:

$$CO_2 \text{ emission} = \text{Population}^*(\text{GDP}/\text{Population})^*(\text{Energy}/\text{GDP})^*(CO_2/\text{Energy})$$

Here $C = (C/E)^*E$

$= (C/E)^*(E/G)^*G$

$= (C/E)^*(E/G)^*(G/P)^*P$ (1)

Where C= CO_2 emission; E=Energy Consumption; G=GDP; P=total population

C/E=the carbon intensity of energy, representing the structure of energy

E/G=the energy intensity of GDP, representing energy efficiency

G/P=the per capital GDP, representing a country's development stage

2. Index decomposition analysis (IDA) and structural decomposition analysis (SDA)

Based on Yaka Identity, numerous attempts have been made to capture the key driving forces influencing the changes of aggregate CO_2 emission, and further extend the method into the sector level. Due to the debates of research methodology selection, Ang (20004) points out that four criteria needs to be followed in terms of method selection, and they are (1) theoretical foundation, (2) adaptability, (3) ease of use, and (4) ease of result interpretation. Arguably Index decomposition analysis (IDA) and structural decomposition analysis (SDA) are the two most widely used approaches in the literature. Xu and Ang (2013) conduct a comprehensive review of the evaluation of the IDA approach and its applications to the carbon emission field. Su and Ang (2012) compare the differences between IDA and SDA, and offer a guideline on method selection.

(1) IDA Approach

In general, IDA decompose the aggregate CO_2 emission into several components, including Divisia, Lasperyres, Paasche, Fisher, and Marshall-Edgeworth index approaches and their transformations (Wang et al., 2015), where the Divisia was the more widely applied in previous empirical studies. Ang (2004) introduces the logarithmic mean Divisia index (LMDI) approach due to its fitness to the four criteria mentioned in his paper. Based on the IDA approach, normally we assume that an aggregate CO_2 emission of a particular sector can be divided into several sub-categories. Here we borrow the models presented in Xu and Ang (2013)'s paper. The aggregate measure of interest is assumed as the summation of sub-category values, and the sub-categories are industry sector. The sub-category $Y(X_1, X_2, \cdots, X_n)$ is a function of N factors, *and* $Y(X_1, X_2, \cdots, X_n) = X_1, X_2, \cdots, X_n$ the model is normally specified as follows:

$$C = \sum_{j=1}^{m} C_j = \sum_{j=1}^{m} Y_i(X_1, X_2, \cdots, X_n) = \sum_{j=1}^{m} X_{j,1}, X_{j,2}, \cdots, X_{j,n} \quad (2)$$

Where C is the aggregate measure, and $C_j = Y_j(X_1, X_2, \cdots, X_n)$ is the sub-category of the aggregate and for the J_{th} secotr, $X_{j,I}$ is the value of i_{th} factor at the J_{th} sector, and m is the number of sub-categories.

In additive decomposition, an overall change of the aggregate from C_0 at time 0 to C_t at time T can be measured as ΔC_{tot}

$$\Delta C_{tot} = C_t - C_0 \quad (3)$$

$$\Delta C_{tot} = \sum_{i=1}^{n} \Delta C_{x_i} \quad (4)$$

The model can be further modified if we throw four commonly used factors into the model. Let C be the aggregate emissions, and C_i be the emission from sub-category i, A be the aggregate activity level, $S_i(=A_i/A)$ be the activity share, $EI_i(=E_i/A_i)$ be the sub-category energy intensity, and $CF_i(=C_i/E_i)$ be the carbon factor of sub-category i, then the model can be specified as follows:

$$C = \sum_i C_i = \sum_i A \frac{A_i}{A} \frac{E_i}{A_i} \frac{C_i}{E_i} = \sum_i A \times S_i \times EI_i \times CF_i \quad (5)$$

The model can be further extended if the product of fuel mix $F_{ij}(=E_{ij}/E_i)$ and the emission coefficient $U_{ij} = (C_{ij}/E_{ij})$ are considered. The number of factors employed in the study normally is either four or five for most IDA studies (Xu and Ang, 2012).

$$C=\sum_i\sum_j C_{ij}=\sum_i\sum_j A\frac{A_i}{A}\frac{E_i}{A_i}\frac{E_{ij}}{E_i}\frac{C_{ij}}{E_{ij}}$$
$$=\sum_i\sum_j A\times S_i\times EI_i\times F_{ij}\times U_{ij} \quad (6)$$

If we assume that the emission coefficient of a particular fuel remain consistent during a short period of time, then the model can be simplied as follows:

$$C=\sum_i\sum_j A\times S_i\times EI_i\times F_{ij} \quad (7)$$

(2) Input Output Analysis

Compared to IDA, SDA approach is based on the input-output model to analyse the impact of production categories on CO_2 emission. Wang et al. (2015) state that findings based on SDA approach are more completed, but the approach requires more data. The major reason is that input-output tables are not constructed annually in many countries, which restricts its popularity. IDA, on the other hand, only requires sector level data, indicating that this approach is more data friendly. In addition, IDA can adopt additive and multiplication decompositions, while only additive decomposition can be applied in SDA (Su and Ang, 2012; Zhang et al., 2015). The standard Leontief I-O model can be written as:

$$X=Z_d{}^*1+Y=A_dX+Y \quad (8)$$

Where $X=(X_i)_{m\times 1}$ is the vector of total outputs, $Z_d=(Z_{d,ij})_{m\times m}$ is the matric of domestic intermediate demands, $Y=(Y_j)_{m\times 1}$ is the vector of final demand, and $A_d=Z_d(\hat{X})^{-1}=(A_{d,ij})_{m\times m}$ is the matrix of domestic production coefficients. Therefore, equation (8) can be rearranged as follows:

$$X=(1-A_d)^{-1}Y=L_dY \quad (9)$$

Where $L_d=(1-A_d)^{-1}=(L_{d,ij})_{m\times m}$ is the domestic Leontief inverse matrix. In equation (9), final demands care viewed as the exogenous driving forces in the model. To apply equation (9) to carbon studies, then the carbon emission from production can be formulated as follows:

$$\mathrm{C}=1'\cdot C=f'X=f'L_dY=\sum_{i,j=1}^{m} f_iL_{d,ij}Y_j=\sum_{i,j=1}^{m} C_{ij} \quad (10)$$

Where $C=(C_i)_{m\times 1}$ is the vector of direct CO_2 emissions, $f=(\hat{X})^{-1}C=(f_i)_{m\times l}$ is the vector of emission intensity, $C_{ij}=f_iL_{d,ij}Y_j$ is the CO_2 emissions from sub-category (I,j), and the total number of sub-categories is m^2.

Similarly, an overall change of the aggregate from C_0 at time 0 to C_t at time T can be measured as $\varDelta C_{tot}$, which can be further decomposed into the following three effects:

$$\varDelta C_{tot}=\varDelta C_{int}+\varDelta C_{str}+\varDelta C_{fdm} \quad (11)$$

Where $\varDelta C_{int}$ is the emission intensity effect, $\varDelta C_{str}$ is the Leontief structure effect, $\varDelta C_{fdm}$ is the final demands effect. And the $\varDelta C_{str}$ can be further divided into two sub-effect as:

$$\varDelta C_{str}=\varDelta C_{ims}+\varDelta C_{inp} \quad (12)$$

Where $\varDelta C_{ims}$ is the imported share effect, and $\varDelta C_{inp}$ is the total input technology effect.

Hoekstra and van den Bergh (2003) compare SDA and IDA in a number of aspects. Recently, Su and Ang (2012) further update the literature in this area by comparing the development of these two approaches after 2000. First of all, the difference in data requirement fundamentally distinguishes these two approaches. SDA relies on the I-O model framework, while IDA only needs sector level data. Consequently, SDA account for the direct effect while IDA deal with the direct effect of carbon emission. Secondly, both multiplicative and additive decompositions can be applied in IDA approach, while only the additive decomposition from is normally used in SDA studies. Consequently, the simplicity of IDA allows considerable flexibility in problem formulation, while the I-O table allows SDA to have a more complete analysis (Su and Ang, 2012). Third, the number of factors used in IDA approach was typically less than that in SDA approach.

For example, the number of factors used in IDA was normally less than five, while the number of factors studied in SDA varies from two to more than ten. Fourth, IDA studies are more likely to focus on the energy consumption and carbon emission in a particular sector, such as power, transportation, or building industry. SDA studies, on the other hand, tend to provide a broader picture of the whole economy of one or few regions or countries.

3. Logarithmic Mean Divisia Index (LMDI) and Mean Rate-of-Change Index(MRIC)

However, several new decomposition methods in the additive form have been introduced in the literature since 2000, including LMDI methods, the S/S method (Shapley, 1953; Sun, 1998), the data envelopment analysis (DEA), the production theoretical decomposition analysis (PDA) (Zhou and Ang, 2008; Li, 2010) and MRCI method. There is overwhelming majority of recent studies uses LMDI due to its theoretical foundation, adaptability, ease of use, and interpretation of results in the context of IDA (Xu and Ang, 2013). Su and Ang (2012) also point out that the gap between IDA and SDA with regard to the decomposition methods has been narrowed due to the development in methodologies. Additionally, methods used in both techniques provide fairly consistent empirical results, and only differ when it comes to some fine details.

Ⅳ. Conclusion

This paper provides a comprehensive review and analysis of research that addresses the climate change and CO_2 emission, and makes several noteworthy contributions to the carbon research literature by providing a new understanding of the relevant literature and process. This study thereby proves to be particularly valuable to countries that are seeking solutions to minimize the potential climate risk and achieve rapid economic growth simultaneously especially after the global financial crisis. The mixed results of empirical studies are primarily due to methodological problems, choice of variables, and data availability. The designs of environmental policies vary from one country to another, and it is therefore difficult for researchers to draw convincing conclusions from comparison studies. The overall conclusions and policy implications from the literature show: (1) Increase in overall economic development and international trade are inevitably lead to increase in carbon emission, and vice versa. (2) Technology progress plays a critical role in carbon emission reduction for most sectors in most countries. (3) Diversities in the energy consumption and carbon emission patterns are found among different sectors and countries, therefore, diversities in development paths towards a low carbon economy are expected, especially in developing countries. (4) The development in research methods has increased the consistency of empirical findings based on different analysis approaches.

It is also well known that climate risk is a challenge for everyone in this world. Therefore, the low carbon economy is now a global phenomenon. Keeping global warming under 2 ℃ is mission impossible if a strong international legal agreement on climate change is absent. However, the research and actions in this area is very lean. Without an effective and equitable international agreement, it is difficult for individual country to underpin carbon actions or policies at national level because of lacking an international foundation of multilateral rules and principles. Countries need to work together to achieve a good result more than the sum of uncooperative national actions. Accordingly, corporate reporting on corporate social responsibility and corresponding strategies should be integrated with financial reports and standardised. Additionally, the multiple benefits and cost of a low carbon economy needs to be further investigated. The cost aspect is easy to understand, but benefits part is difficult to be quantified. In particular, new climate economy report (2014) states that it is important to investigate how the size and time paths of various benefits and costs differ across countries, which could provide guidance on the issuance of environmental policies.

In short, the world economy has growth strongly in the last two decades, and so does the GHG emission. The global CO_2 emission from energy use increased by 3% per year since 2000, which leads to a series of severe consequences. Immediate action must be taken because it can take more than 25 years for CO_2 molecules to reach the upper atmosphere, and cause the "greenhouse effect" of trapping heat. Thus, we need to reduce the GHG emission today and over the next 15 years to moderate the climate change in 2050. Even it is a very difficult mission, but it must be accomplished.

Acknowledgement

The author, Larry Li is grateful to Economic Research Centre, Graduate School of Economics of Nagoya University to host Larry Li as an Visiting Associate Professor to conduct the research during Oct. 2015 to Feb. 2016.

This is also a part result of the carbon emissions trading program at the Center for Hubei Cooperation Innovation of Emissions Trading System, where Jinjun Xue serves as a chief scientist. We also thank The Academic Research Foundation of All Japan Banks (全国銀行学術研究振興財団) for its financial support to this joint study.

Reference:

Agnihotri, B. (2015), VW's Dieselgate Scandal Could Cost Up To $87 Billion In Total, Oilprice.com, available at: http://oilprice.com/Energy/Energy-General/VWs-Dieselgate-Scandal-Could-Cost-Up-To-87-Billion-In-Total.html, accessed on 01 Nov, 2015.

Andreoni, V. and S. Galmarini (2012), European CO_2 Emission Trends: A Decomposition.

Analysis for Water and Aviation Transport Sectors. *Energy* 45 (1), 595-602.

Ang, B.W. (2004), Decomposition Analysis for Policymaking in Energy: Which is the Preferred Method?, *Energy Policy* 32(9), 1131-1139.

Benz, E. and J. Hengelbrock (2008), Liquidity and Price Discovery in the European CO2 Futures Market: An Intraday Analysis. 21st Australasian Finance and Banking Conference 2008 Paper. Available at SSRN: http://ssrn.com/abstract=1143923 , accessed on 01 Nov, 2015.

Benz, E. and S. Truck (2009), Modeling the price dynamics of CO2 emission allowances, *Energy Economics* 31, 4-15.

Bushnell, J.B. H., Chong and E.T. Mansur (2013), Profiting from Regulation: Evidence from the European Carbon Market, *American Economic Journal: Economic Policy* 5, 78-106.

Carraro, C. A., Favero and E. Massetti (2012), Investments and Public Finance in Green, Low Carbon, Economy, *Energy Economics* 34, S15-S28.

Conrad, C. D., Rittler, and W. Waldemar (2012), Modeling and Explaining the Dynamics of European Union Allowance prices at High Frequency, *Energy Economics* 34, 316-326.

Daskalakis, G. D., Psychoyios and, R. N. Markellos (2009), Modelling CO2 Emission Allowance Prices and Derivatives: Evidence from the European Trading Scheme, *Journal of Banking and Finance* 33, 1230-1241.

Davis, S.J. G.P. Peters and K. Caldeira (2011), The Supply Chain of CO_2 Emission, *Proceedings of the National Academy of Science of the United States of America*, 108(45), 18554-18559.

Davis, W.B. A.H., Sanstad and J.G. Koomey (2003), Contributions of Weather and Fuel Mix to Recent Declines in US Energy and Carbon Intensity, *Energy Economics* 25, 375-396.

Dion, S. (2015), A World Price for Carbon, *Harvard International Review*, Spring, 49-53.

Dong, Yi.L. M., Ishikawa and T. Hagiwara (2015), Economic and Environmental Impact Analysis of Carbon Tariffs on Chinese Exports, *Energy Economics* 50, 80-95.

Dowell, G. S., Hart and B. Yeung (2000), Do Corporate Global Environmental Standards Create or Destroy Value? *Management Science* 46(8), 1059-1074.

European Commission (2009), Directive 2009/29/EC of the European Parliament and of theCouncil of 23 April 2009 Amending Directive 2003/87/EC So As To Improve andExtend the Greenhouse Gas

Emission Allowance Trading Scheme of the Community,Brussels.

EU EUS Handbook (2013), available at: http://ec.europa.eu/clima/publications/docs/ets_handbook_en.pdf

Fahimnia, B., J. Sarkis, F. Dehghanian, N. Banihashemi, and S. Rahman (2013), The Impact of Carbon Pricing on a Closed-Loop Supply Chain: An Australian Case Study, *Journal of Cleaner Production* 59, 201-225.

Figuerola-Ferretti, I. and J. Gonzalo (2010), Modelling and Measuring Price Discovery in Commodity Markets. *Journal of Econometrics* 158, 95-107.

Flapper, S.D.P., J.A.E. Nunen and L.N.V. Wasenhove (2005), *Managing Closed-Loop Supply Chains*. Springer, Berlin.

Fleischmann, M., H.R. Krikke, R. Dekker and S.D.P. Flapper (2000), A characterisation.

Fusaro, P. C (2007), Energy and Environmental Hedge Funds, *Commodities Now*, 1-2, September.

Gallego, B. and M. Lenzen (2005), A Consistent Input-Output Formulation of Shared Consumer and Producer Responsibility, *Economic Systems Research* 17(4),365-391.

Gonzalez, D. and M. Martinex (2012), Decomposition Analysis of CO2 Emissions in the Mexican Industrial Sector, *Energy for Sustainable Development* 16, 204-215.

Goulder, I., M. Hafstead and M. Dworsky (2010), Impacts of Alternative Emissions Allowance Allocation Methods under a Federal Cap-and-Trade Program, *Journal of Environmental Economics and Management* 60, 161-181.

Gray, W.B. and R.J. Shadbegain (1995). Pollution Abatement Costs, Regulation, and Plant-Level Productivity, NBER Working Paper, No. 4994.

Hamiltion, J. (1995), Pollution as News: Media and Stock Market Reactions to the Toxics Release Inventory Data, *Journal of Environmental Economics and Management* 20, 986-1014.

Hart, S.L. and G. Ahuja (1996), Does it Pay to be Green? An Empirical Examination of the Relationship between Emission Reduction and Firm Performance, *Business Strategy and the Environment* 5, 30-37.

Hatzigeorgiou, E., H. Polatidis, and D. Haralambopoulos (2008), CO_2 Emissions in Greece for 1990-2002: A Decomposition Analysis and Comparison of Results Using the Arithmetic Mean Divisia Index and Logarithmic Mean Divisia Index techniques, *Energy* 33, 492-499.

Havranek, T., Z. Irsova, K. Janda, and D. Zilberman (2015), Selective Reporting and the Social Cost of Carbon, *Energy Economics* 51, 394-406.

Hoekstra, R. and J.C.J.M. van Den Bergh (2003), Comparing Structural and Index Decomposition Analysis, *Energy Economics* 25(1), 39-64.

Jeswiet, J. and S. Kara (2008), Carbon emissions and CES^{TM} in manufacturing, *CIRP Annals - Manufacturing Technology* 57(1), 17-20.

Jong, T., O. Couwenberg, and E. Woerdman (2014), Does EU Emission Trading Bite: An Event Study, *Economic Policy* 69, 510-519.

Kaya, Y. and K. Yokoburi (1997), *Environment, Energy, and Economy: Strategies for Sustainability.* United Nations University Press, Tokyo

Kim, K. and Y.Kim (2012), International comparison of industrial CO2 emission trends and the energy efficiency paradox utilizing production-based decomposition, *Energy Economics* 34, 1724-1741.

Koch, N. and A. Bassen (2013), Valuing the Carbon Exposure of European Utilities: The role of Fuel Mix, Permit Allocation and Replacement Investments. *Energy Economics* 36, 431-443.

Kwon, T.H. (2005), Decomposition of Factors Determining the Trend of CO2 Emissions from Car travel in Great Britain (1970-2000), *Ecological Economics* 53, 261-275.

Lewis, J. I. (2010), The Evolving Role of Carbon Finance in Promoting Renewable Energy Development in China, *Energy Policy* 38, 2875-2886.

Li, B.Q. and X. J. Lei (2015), Carbon Emission Reduction in China's Food Industry, *Energy Policy* 86, 483-492.

Li, X., K. Feng, Y.L. Siu, and K. Hubacek (2015), Challenges Faced When Energy Meets Water: CO_2 and Water Implications of Power Generation in the Northern Regions of China, *Renewable and Sustainable Energy Review*, In press.

Lin, B.Q. and K.R. Du (2015), Modeling the Dynamics of Carbon Emission Performance in China: A Paametric Malmquist Index Approach, *Energy Economics* 49, 550-557.

Li, M. (2010), Decomposing the Change of CO_2 Emissions in China: A Distance Function Approach. *Ecological Economics* 70, 77-85.

Lin, B.Q., and X.J. Lei (2015), Carbon Emission Reduction in China's Food Industry, *Energy Policy* 86, 483-493.

Lise,W. (2006), Decomposition of CO_2 Emissions over 1980-2003 in Turkey. *Energy Policy* 34, 1841-1852.

Liu, H.G., W.D. Liu, X. M. Fan, and W. Zou (2015), Carbon Emission Embodied in Demand-Supply Chains in China, *Energy Economics* 50, 294-305.

Liu, Z., Guan, D., Wei, W., Davis, S., Ciais, P., Bai, J., Peng, S., Zhang, Q., Hubacek, K., Marland, G., Andres, R., Brown, D., Lin, J., Zhao, H., Hong, C., Boden, T., Feng, K., Peters, G., Xi, F., Li, Y., Zhao, Y., Zeng, N., He, K., (2015), Reduced Carbon Emission Estimates from Fossil Fuel Combustion and Cement Production in China, *Nature* 524, 335-338.

Maclean, I.M.D., and R.J. Wilson (2011), Recent Ecological Responses to Climate Change Support Predictions of High Extinction Risk, *Proceedings of the National Academy of Science of the United States of America* 108 (30), 12337-12342.

Marques, A., J. Rodrigues, M. Lenzen, and T. Domingos (2012), Income-Based Environmental Responsibility. *Ecological Economics* 84, 57-65.

Marques, A., J. Rodrigues, and T. Domingos (2013), International Trade and the Geographical Separation between Income and Enabled Carbon Emissions, *Ecological Economics* 89,162-169.

Meng, B., J.J. Xue, K. S. Feng, D.B. Guan, and X. Fu (2013), China's Inter-Regional Spillover of Carbon Emissions and Domestic Supply Chains, *Energy Policy* 61, 1305-1321.

Michaels, J.P. (2008). Evidence for "Publication Bias" Concerning Global Warming in Science and Nature, Energy and Environment, 19 (2), 287-301

Mizrach, B., and Y. Otsubo (2014), The Market Microstructure of the European Climate Exchange, *Journal of Banking and Finance* 39, 107-116.

Munksgaard, J., and K.A. Pedersen (2001), CO2 Accounts for Open Economies: Producer or Consumer responsibility? *Energy Policy* 29, 327-334.

New Climate Economy Report, (2014), available at: http://2014.newclimateeconomy.report

Oberndorfer, U. (2009), EU Emission Allowances and the Stock Market: Evidence from the Electricity Industry. *Ecological Economics* 68, 1116-1129.

Oestreich, A. M. and Tsiakas. I. (2015), Carbon Emissions and Stock Returns: Evidence from the EU Emissions Trading Scheme, *Journal of Banking and Finance* 58, 294-308.

Paolella, M.S. and, L. Taschini (2008), An Econometric Analysis of Emission Trading Allowances, *Journal of Banking and Finance* 32, 2022-2032.

Peters, G.P. and E.G. Hertwich (2008), Post-Kyoto Green House Gas Inventories: Production versus Consumption, *Climate Change* 86, 51-66.

Peters, G.P., C.L. Weber, D. Guan, and K. Hubacek (2007), China's Growing CO_2 Emission-A Race between Increasing Consumption and Efficiency Gain, *Environmental Science and Technology* 47(17), 5939-5944.

Ramiah, V., B. Martin, and I. Moosa (2013), How does the Stock Market React to the Announcement of Green Policies? *Journal of Banking and Finance* 37, 1747-1758.

Rittler, D. (2012), Price Discovery and Volatility Spillovers in the European Union Emissions Trading Scheme: a High-Frequency Analysis. *Journal of Banking and Finance* 36, 774-785.

Reuters (2015), Volkswagen could face $18 billion penalties from EPA http://www.reuters.com/article/us-usa-volkswagen-idUSKCN0RI1VK 20150918

Sarkis, J. (2003), A Strategic Decision Framework for Green Supply Chain Management, *Journal of Cleaner Production* 11, 397-409.

Saveyn, B., L. Parousos, and J. C. Ciscar (2012), Economic Analysis of a Low Carbon Path to 2050: A Case for China, India and Japan, *Energy Economics* 34, 451-458.

Schultz, E. and J. Swieringa (2014), Catalysts for Price Discovery in the European Union Emission Trading System, *Journal of Banking and Finance* 42, 112-122.

Seifert, J., M. Uhrig-Homburg, and M. Wagner (2008), Dynamic Behavior of CO_2 Spot Prices, *Journal of Environmental Economics and Management* 56, 180-194.

Seuring, S. (2013), A Review of Modeling Approaches for Sustainable Supply Chain Management. *Decision Support Systems* 54(4), 1513-1520.

Shapley, L.S. (1953), A Value for N-Person Games. Contributions to the Theory of Game II, Princeton University Press, 307-317.

Sijm, J., K. Neuhoff, and Y. Chen (2006), CO_2 Cost Pass-Through and Windfall Profits in the Power Sector, *Climate Policy*, 6(1), 49-72.

Smale, R., M. Hartley, C. Hepburn, and J. Ward (2006), The Impact of CO_2 Emissions Trading on Firm Profits and Market Prices, Climate Policy 6(1), 31-48.

Swanson, K.L. (2013), Emerging Selection Bias in Large-Scale Climate Change Simulations, *Geophysical Research Letters*, 40 (12), 3184-3188.

Su, B. and B.W. Ang (2012), Structural

Decomposition Analysis Applied to Energy Emissions: Some Methodological Developments, *Energy Economics* 34, 177-188.

Suh, S. (2006), Are Services Better for Climate Change? *Environmental Science and Technology* 40, 6555-6560.

Sun, J. (1999), Decomposition of Aggregate CO_2 Emissions in the OECD: 1960-1995. *Energy Journal* 20, 147-155.

Sundarakani, B., R. de Souzab, M. Goh, S. M. Wagner, and S. Manikandan (2010), Modeling Carbon Footprints across the Supply Chain, *International Journal of Production Economics* 128 (1), 43-50.

UNEP, (2010), The emission gap report. Are the Copenhagen Accord Pledges Sufficient to Limit Global Warming to 2°C or 1.5°C? http://hqweb.unep.org/publications/ebooks/emissionsgapreport/2010.

Veith, S., J. Werner, and J. Zimmermann (2009), Capital Market Response to Emission Rights Returns: Evidence from the European Power Sector. *Energy Economics* 31, 605-613.

Gilbert, D. and S. Kent (2015), BP Agrees to Pay $18.7 Billion to Settle Deepwater Horizon Oil Spill Claims, Wall Street Journal, available at http://www.wsj.com/articles/bp-agrees-to-pay-18-7-billion-to-settle-deepwater-horizon-oil-spill-claims-1435842739, assessed 2 July 2015.

Wall Street Journal, (2015), BP Agrees to Pay $18.7 Billion to Settle Deepwater Horizon Oil Spill Claims, available at: http://www.wsj.com/articles/bp-agrees-to-pay-18-7-billion-to-settle-deepwater-horizon-oil-spill-claims-1435842739.

Wang, Q.W., Y.H. Chiu, and C.R. Chie (2015), Driving Factors behind Carbon Dioxide Emission in China: A Modified Production-Theoretical Decomposition Analysis, *Energy Economics* 51, 252-260.

Wier, M. (1998), Sources of Changes in Emissions from Energy: A Structural Decomposition Analysis. *Economic System Resource* 10, 99-112.

Wu, L.B. and W. Q. Tang (2014), Low-Carbon Tariff Theory, in Xue.J.J. (Eds), *Low-Carbon Economics: Theory and Application*, 191-205, Social Sciences Academic Press (China) and World Scientific, Singapore.

Xu, X.Y., and B.W. Ang (2013), Index Decomposition Analysis Applied to CO2 Emission Studies, *Ecological Economics* 93, 313-329.

Xue, J. J. (2014), Low-Carbon Economics: *Theory and Application*, Social Sciences Academic Press (China) and World Scientific, Singapore.

Yabe, N. (2004), An Analysis of CO2 Emissions of Japanese Industries during the Period between 1985 and 1995. *Energy Policy* 32, 595-610.

Zhang, X.P., Y.K. Tan, Q. L. Tan, and J.H. Yuan (2012), Decomposition of Aggregate CO2 Emissions within a Joint Production Framework, *Energy Economics,* 34, 1088-1097.

Zhang, Y.G. (2013), The Responsibility for Carbon Emissions and Carbon Efficiency at the Sectoral Level: Evidence from China, *Energy Economics* 40, 967-975.

Zhang, Y.G. (2015), Provincial Responsibility for Carbon Emission in China under Different Principles, *Energy Policy* 86, 142-153.

Zhang, Y.G. and Z.P. Tang (2015), Driving Factors of Carbon Embodied in China's Provincial Export, *Energy Economics* 51, 445-454.

Zhang, Z.K., J. Guo, and G.J.D. Hewings (2014), The Effect of Direct Trade within Chin on Regional and National CO_2 Emissions, *Energy Economics* 46, 161-175.

Zhou, P., B.W. Ang, and J.Y. Han (2010), Total factor carbon emission performance: A Malmquist index analysis, Energy Economics 32(1), 194-201.

Zhu, Q. and J. Sarkis (2004), Relationships between Operational Practices and Performance among Early Adopters of Green Supply Chain Management Practices in Chinese Manufacturing Enterprises *Journal of Operations Management* 22, 265-289.

(School of Economics, Finance and Marketing, RMIT University, Australia)
(Economic Research Center, Graduate School of Economics, Nagoya University)