V.R.F. Series

No.485
Jan 2014

Inter-firm Cooperation on Carbon Emission Reduction in China

Wang Zhaohua

日本貿易振興機構 アジア経済研究所

INSTITUTE OF DEVELOPING ECONOMIES, JAPAN EXTERNAL TRADE ORGANIZATION

Acknowledgements

There are many people to thank, and first of all, I would like to extend my deepest gratitude to the Institute of Developing Economies-Japan External Trade Organization (IDE-JETRO) for giving me such a fine opportunity as a visiting research fellow. I would like to express my sincere appreciation to all the staff and researcher of IDE for their support and help throughout my stay in Japan and also throughout the process of my research. It was my first so long time visit to Japan, and I was not able to speak a single Japanese word confidently. Yet, I was given many opportunities to talk and discussion with so many excellent scholars of IDE in English, which eventually enriched my knowledge and research interest.

In particular, I would like to express my sincere thanks to my counterpart, Ms. Etsuyo Michida, for her valuable suggestion and criticisms on my research report. And I am also thankful to the Environment Nature Resource Studies Group colleagues, including Senior Research Fellow Kenji Otsuka, Senior Research Fellow Michikazu Kojima, and other research group colleagues, including Dr. Bo Meng, Dr. Zhe Ren, Dr. Mami Yamaguchi, Chief Senior Researcher Yasuo Onishi, Dr. Hisatoshi Hoken, Mr. Masahiro Morinaga, and so on.

I am specially grateful to Takeo Masuda, Kumi Manda, Atsuko Hirakata and Takao Tsuneishi (now retired) provided me with guidance even prior to my arrival in Japan, assisting greatly with logistical issues and cultural activities.

Finally, I would like to thank all the other VRFS who were with me at IDE for allowing me to enjoy the cozy international atmosphere and global friendship.

This research is also supported by the National Natural Science Foundation of China (Reference Nos. 71173017).

Table of contents

List of Tables and Figures

Tables

Figures

Abstract

Due to increasing energy scarcity and pressures from climate change, Chinese industrial firms have struggled to implement practices to reduce their energy consumption and CO_2 emissions. However, it is not clear whether these practices can improve the environmental or economic performance of these companies. The determinants that drive or hinder the implementation of these practices are also not known. Therefore, this paper describes an empirical analysis of a total of 85 questionnaires from iron & steel firms across China. A regression analysis was applied in this paper to verify the relationship among CO_2 reduction practices, determinants and performance. The results show that although some CO_2 reduction practices can result in significant environmental performance, their impacts on the improvement of economic performance are less clear.

Inter-firm cooperation within industrial chains has become another option to deal with carbon emission problems. Three types of carbon reduction cooperation are classified in this paper: (1) cooperation with suppliers and customers; (2) cooperation with competitors or surrogates; (3) cooperation by waste resource exchange through industrial symbiosis. Moreover, a conceptual model was given to describe the relationship between carbon reduction cooperation and its determinants. The results show that the demand of carbon reduction from other stakeholders on the industrial chains is the main driver for the firms to cooperate on carbon emission reduction, and defective cooperation mechanism is the main barrier. The effects of financial pressure on the cooperation are various according to the different cooperative categories.

1. Introduction

With international communities having increasingly recognized the severity of climate change, the pressure for reduction of CO_2 emissions has become more prominent. China is one of world's biggest emitters, accounting for 24% (about 6.92 billion tons) of global CO_2 emissions in 2009 (IEA, 2011) .The pressure on China to reduce CO_2 emissions increased greatly following the adaption of the Kyoto Protocol in 1997 and follow-up conferences such as Cancun in 2010. In many of these negotiation processes of recent years, China has been pressured by developed countries and some developing counties who are affected directly by climate change, to promise a concrete goal for reductions (Liu et al., 2008) . In addition, there are also great pressures resulting from domestic economic development. According to the estimate by Li et al.(2012), China will need to cut 1651Mt of carbon emission in 2020 in order to achieve the target of reducing CO_2 emissions per unit of GDP by 40–45% compared to 2005, even in a slow economy growth scenario.

Industrial sector is the biggest contributor for energy consumption and carbon emission in China, which accounts for more than 70% of total energy consumption (Liu et al. 2010). There are many energy intensive industries in China play the important role in the rapid growth of economy. Take iron & steel industry (ISI) for example, it ranks as the third biggest CO_2 emitter in China (after the power and construction material sectors), due to its coal intensive energy structure and high consumption of limestone. At present, it accounts for 10% of total domestic CO_2 emissions and 35-40% of CO_2 emissions in major cities (Zeng et al., 2009). China is the world's largest steel producer with rapid growth every year (Worldsteel, 2010). However, there is a concern that the energy efficiency of ISI in China lags far behind the level of the more advanced ISI. Its energy consumption per ton of steel is 15–20% higher than the best international level (Wang, 2007). Therefore, the industrial firms of China face more serious environmental burden, and have to take more responsibility on carbon emission reduction. It is imperative to mitigate the incremental pressures of CO_2 emissions by focusing on the industrial firms' practices of carbon emission reduction.

Technology innovation on energy efficiency is one of the important ways for energy intensive industrial firms to reduce their carbon emission, which has also get lots of attentions from research scholars. In China, large scale of energy intensive industrial equipments have been abandoned, and many intensive energy consumed firms have been forced to shut down due to the energy efficiency improvement as well as regulations' controlling. For instance, energy intensive productivities of 31.22 Mt iron and 27.94Mt steel were obsoleted in 2011, which involved more than 150 industrial firms (MIIT 2011). Cleaner energy substitution is considered as another choice for industrial firms to solve their heavy carbon emission problems. Renewable energy (such as solar power) has been more and more used in the industrial production process. Although there have been great improvement on energy efficiency and energy structure in China, the carbon emission still increases rapidly every year because of obvious economic growth. Liu et al. (2010) pointed out that industrial technology innovation could only contribute 12%-14% to the national target of reducing 40–45% CO_2 emissions per unit of GDP in 2020 comparing with 2005. It is hard to achieve this target merely depending on technology innovation. Above all, industrial firms still confront serious carbon emission reduction pressures. It is indicated that the single firm's practices on carbon emission reduction (e.g. technology innovation by firms themselves) are difficult to satisfy the increasing carbon reduction demand. More carbon emission reduction paths need to be introduced as the supplements for China to confront the increasing carbon emission pressures.

Many scholars have begun to recognize the potential capacity of carbon reduction through industrial chains. Zhu and Geng (2013) discussed the drivers and barriers for Chinese manufacturers cooperating with their supplies and customers to meet the energy saving and emission reduction goals. And closed-loop supply chain become one of the options to deal with environmental and emission problems, which are being considered worldwide (e.g. Korhonen and Snäkin, 2005; Lieckens and Vandaele 2007; Pochampally et al. 2009). However, most of these researches on carbon emission reduction within industrial chains combined with other environmental issues, such as eco-product design (Hugo and Pistikopoulos 2005) and design of sustainable supply chain (Chaabane et al. 2012). Few studies are focusing specially on carbon reductions in the view of cooperation through industrial chains. Therefore, it is not clear how industrial firms cooperate through the industrial chains in order to reduce their carbon emissions. And whether these inter-firm cooperation practices have significant effects on carbon reduction or economic performance need further investigation.

Therefore, this study is designed to enrich the current researches to find out the status of industrial firms' practices on carbon emission reduction. CO_2 emission reduction practices refer to all kinds of activities of the company related to carbon reduction. It can include physical measures such as retrofit of energy equipment, as well as managerial measures such as implementation of carbon accounting system. Determinants are defined as the drivers or barriers that influence the implementation of CO_2 abatement practices. Performance includes both economic and environmental performance of industrial companies. Specially, we make a deep study on the inter-firm collaboration on carbon emission reduction. The willingness and effect of the collaboration on industrial firms are explored in this study. Above all, this paper is focusing on solving the following questions：

- What CO_2 emission reduction practices are being employed by Chinese industrial firms？
- Which determinants drive or hinder the implementation of these practices？
- Are there a broad willingness for the industrial firms to collaborate on carbon emission reduction？

The paper is organized as follows: To begin with, we give a broad discussion about CO2 emission structure and abatement practices with a case study of iron & steel industry in China. This is followed by the detailed exploration about the special carbon reduction practices, namely inter-firm collaboration on carbon emission reduction. The development of a framework of hypotheses with the theoretical lens of institutional theory and resource-based view of the firm is in Section 3. Conclusion is given in the last section of this study.

2. Empirical analysis on carbon emission reduction practices

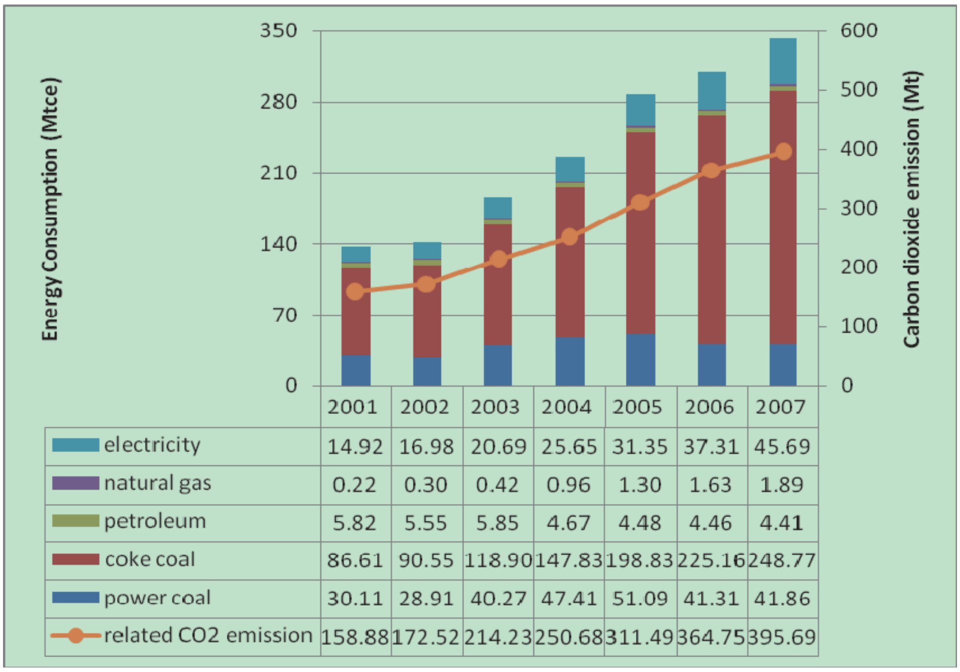
With the increasing burden from energy saving and low carbon production, industrial firms have been gradually realized the importance of carbon emission reduction. How to reduce the carbon emission during the industrial production is groping by many energy intensive manufacturers in China. This section takes iron & steel industry (IS) as an example to identify the practices of carbon emission reduction (CER) for industrial firms.

2.1 CO_2 emission structure of IS industry

The iron and steel sector is one of the largest CO_2 emitters in China. There are three main emission sources in the processes of iron and steel production: (1) the direct, onsite burning of fossil fuels; (2) indirect emission from electricity consumed during production process; and (3) directly, non-energy related emissions (Wang et al., 2007) . It is widely agreed that the first and second sources are the main cause of CO_2 discharges. About 395.69 Mt related CO_2 discharged in 2007 (see in Figure 1), and the amount was expected to grow due to the increasing production and carbon intensive energy structure. Coal is the dominant primary energy source, and is the major source of CO_2 emissions. Take the year 2007 for instance, coal provides about 74.5% of total energy needs, in which coke coal accounted for 85.6% and power coal accounted for 14.4%. Electricity and petroleum are the second and third sources of primary energy. In addition, the energy efficiency of Chinese ISI lags behind the world advanced level. The average consumption per ton of steel in the key Chinese IS enterprises is 15% higher than the world advanced enterprises (Guo and Yin, 2007). It is estimated that there are 705 kg ce (kg coal equivalent) per ton of steel consumed by the key IS enterprises in 2004, 8.3% higher than the world average (Zeng, 2009). Therefore, the corresponding CO_2 emissions should be even higher.

Iron production is the most energy-intensive process, and accounts for nearly 40% of China's total CO_2 emissions emanating from iron and steel sector. Each process of iron making (e.g. coking, sintering, iron-making) consumes more energy per unit of production in comparison to international advanced level (see in Figure 2). There are two main technology paths for transformation of iron into steel: oxygen blown converter and electric arc furnace (EAF). The first path is the dominant technical path in China, and accounts for 81.6% of steel production (IISI, 2005). The electric arc furnace is based on the use of scrap and electricity, while the basic blast furnace (BOF) uses iron ore and coal. It is estimated that the CO_2 emission of BOF is about 1700 kg/t (steel), while the scrap-EAF is only about 400kg/t (Ren and Wang, 2011).

Energy consumption is not the only source of CO_2 emission. CO_2 is discharged during several processes of iron and steel production due to the decarbonization of limestone ($CaCO_3$) and dolomite ($MgCO_3$). There were 42.5 Mt of limestone consumed by ISI in 2007 (Li et al. 2010). It is estimated that the emissions theoretically amount to 0.44 t CO_2/t limestone (Gielen, 1997). This is, as a result, an important source of 18.7 Mt of CO_2 emissions.



	2001	2002	2003	2004	2005	2006	2007
electricity	14.92	16.98	20.69	25.65	31.35	37.31	45.69
natural gas	0.22	0.30	0.42	0.96	1.30	1.63	1.89
petroleum	5.82	5.55	5.85	4.67	4.48	4.46	4.41
coke coal	86.61	90.55	118.90	147.83	198.83	225.16	248.77
power coal	30.11	28.91	40.27	47.41	51.09	41.31	41.86
related CO2 emission	158.88	172.52	214.23	250.68	311.49	364.75	395.69

Fig. 1. Energy structure and related CO_2 emission of Chinese ISI[1]

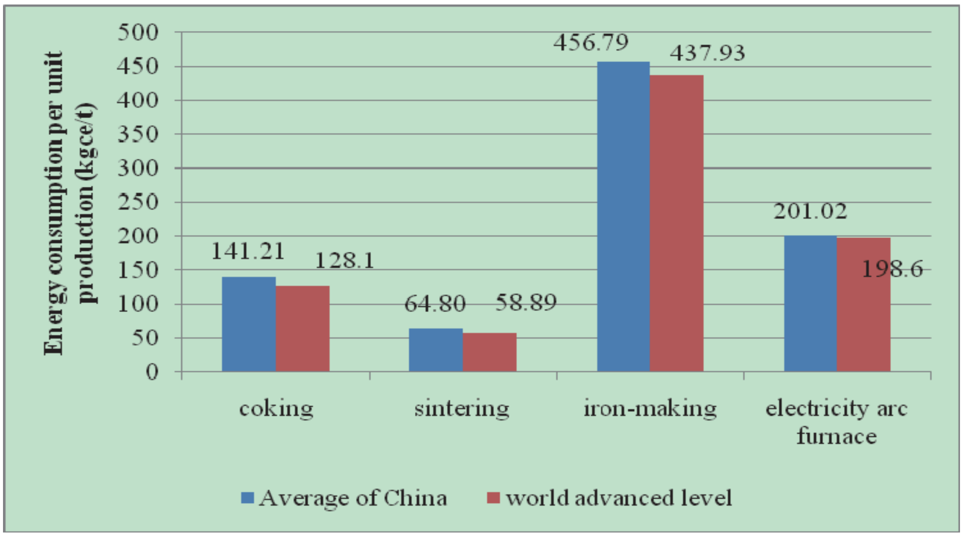


Fig. 2.Energy efficiency of several main processes of ISI

Data source: Zeng et al., 2009

2.2 The practices of CO_2 emission reduction in IS companies

CO_2 reduction channels can be split into two sides: consumption side and production side (Gielen and Moriguchi, 2002). CO_2 reduction from consumption depends on reducing the steel demand, but it is not directly controlled by producers.

---

[1] Data source: the energy consumption data come from National energy statistic year book of China (NBS, 2002~2008); the emission of CO_2 is estimated according to IPCC (2006), which provides carbon emission fomula: carbon emissions= $\sum_i B_i \times C_i$ (i is the type of fuel; B_i is the carbon emission factor of fuel i ; C_i is the consumption of fuel i); the data of B_i are referred to Zhao (2009).

CO_2 reduction from production can be influenced by a number of practices on energy efficiency improvement, fuel substitution, material recycling etc. (Rynikiewicz, 2008).

Increasing energy efficiency is largely dependent on producers' innovation practices. These innovation practices include "technological improvement, application of new techniques, application of new equipment or materials, and structural adjustment of products, techniques or energy consumption" (Zeng et al., 2009). R&D investment is the driving source for the application of technology on energy conservation or carbon abatement (e.g. Carbon capture and storage). It strengthens producers' potential abilities in response to the future pressures from climate change. In addition, production process innovation deals with the radical or incremental innovations that would decrease the CO_2 emissions per ton of material (Rynikiewicz, 2008). It can help to adjust the structure of products and energy consumption to the cleaner ones. Moreover, replacing the equipments with energy efficient ones is often necessary to introduce new materials and technology in order to increase energy efficiency. Here we define all these kinds of enterprises' technological improvement and innovative activities on energy conservation or carbon reduction as "innovation" on energy conservation and carbon reduction. All these innovation activities require large amount of financial and human resource investment.

Recycling of materials, by-products and residues is an effective way to reduce the discharge of CO_2, and proposed by some scholars (e.g. Gielen and Moriguchi, 2002; Rynikiewicz, 2008). There are significant amounts of energy by-products or residual energy generated during the production process in ISI, for example, coke oven gas, blast furnace gas and blast furnace slag. Coke oven gas and blast furnace gas are good substitute of fossil energy. If these gaseous energy carriers are sold, the IS enterprises can not only get economic benefits, but also allocate their carbon content to the user of the gas. The blast furnace slag can be used as a cement substitute. It is estimated that the use of blast furnace slag as a substitution would result in 0.8 t CO_2 saved from the production of 1 ton of cement production (Gielen and Moriguchi, 2002). Some IS companies in China have highlighted the optimization of the flow of material and energy between different processes or with other industries. Zero waste and 4R (reuse, remanufacture, recycle and recover) have become common concepts in their production. For instance, more than 90% of blast furnaces that are above 1000 m^3 have been installed with Top-Pressure Recovery Turbine (TRT) which expected to recover 10 billion kWh every year in China (Huang, 2010).

In addition, strategy of energy conservation and carbon abatement offers the direction of the company to conduct CO_2 abatement in the short-term or long-term future. Several IS companies in China began to draw up their schemes of energy saving and CO_2 reduction. *Baosteel*[2] for example, has formulated "*Management Process of Energy Saving Goal*", which describes the future development of high energy efficiency and resource efficiency of manufacturing processes. And several projects of CO_2 abatement are planned to be implemented in the short-term. An

[2] Baoshan Iron & Steel Co., Ltd (Baosteel) is the largest and most advanced integrated steel company in China, which is located in Shanghai.

industry-scale plant for recovering flue gas from lime kiln will be constructed, which is expected to reduce10000t CO_2 emissions annually (Zou, 2008).

The implementation of carbon crediting mechanism[3] is another practice of IS companies in China related with CO_2 emission reduction. Although it has no direct effect on producers' CO_2 abatement, it can motivate producers to indulge in emission reduction practices. Since carbon trading is becoming an inevitable trend in the world market, credit mechanism can help the company to get the opportunity to change the amount of CO_2 reduction into economic benefits by carbon trading. At present, China has no regulated cap-and-trade carbon market. The IS companies of Chinese are not required to participate in carbon trading in the domestic market. However, some companies have participated in selling their carbon credit to international buyers by CDM project. Moreover, some pressures of carbon trading are coming from the international business through exporting products or being supplied by foreign iron ore companies. Far-sighted companies have realized the opportunities in the carbon trading, and plan to work on the practices related to implementation of carbon crediting mechanism.

2.3 Theoretical hypotheses for the determinants of CER practices

A conceptual model is developed in this section to identify the determinants that drive or hinder the companies' practices of CO_2 emission reduction in ISI, and examine the effect of these determinants on the practices. Besides, the relationship between companies' CO_2 abatement practices and performance (including both economic performance and environmental performance) is also explored as well. Firm size is considered as control variable in this model. Figure 3 is the assumed framework and structure in this paper. It reflects the relationship between CO_2 abatement practices and some specific determinants, and the assumed effects of CO_2 abatement practices on enterprises performance.

[3] Carbon crediting is a concomitant concept of carbon trading. It refers to "a generic term for any tradable certificate or permit representing the right to emit one ton of carbon dioxide" (See http://en.wikipedia.org/wiki/Carbon_credit). Here we use the word "carbon trading mechanism" to epitomize all kinds of activities related with baseline and credit carbon trading like CDM.

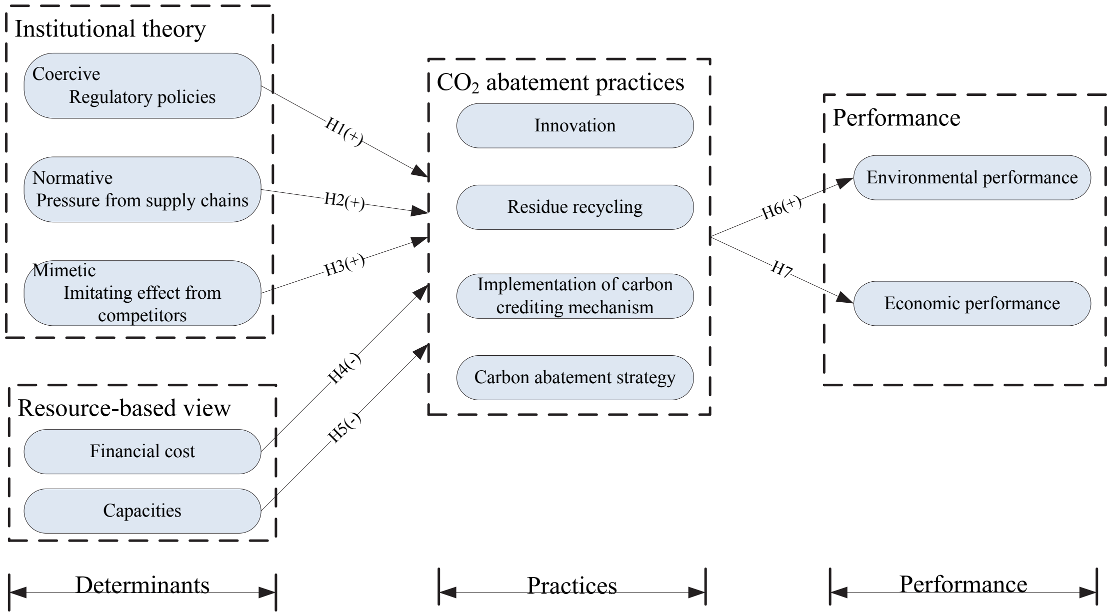


Fig. 3. Conceptual model

Notes: (+) indicates positive effect; (-) indicates negative effect.

Institutional theory and resource-based view are introduced as the theoretical basis for identifying the determinants of CO_2 emission reduction practices in IS companies. It is posited by institutional theory that the drivers of environmental management practices can be motivated by three kinds of determinants: coercive, normative and mimetic (DiMaggio and Powell, 1983). Thus, barriers for proactive environmental management practices can be attributed to the lack of resource and capability from the resource-based view (Ebinger et al., 2006).

Coercive driver refers to the compulsive pressure coming from those in power such as governmental agencies (Rivera, 2004). Environmental regulations can be considered as an important factor for effective practices of energy saving and emission reductions (Jones, 2010). Chinese government has released many environmental regulations to decrease the resource consumption and mitigate the emission problems. Many of these regulations evolve to coercive pressures driving iron and steel companies to implement the practices of energy saving and emission reductions. For instance, it is announced by an administrative decree of State Council that poor productivity of 31.22 Mt iron and 27.94Mt steel must be obsoleted in 2011, involving 154 IS companies in China (MIIT, 2011). Moreover, there are some laws in China enacted to guide the environmental practices. Energy Conservation Law (first effective in 1997 and amended in 2007) specially sets the responsibilities of energy intensive industries (e.g. ISI), and provides criteria for the maximum quota of certain products' energy consumption and the energy efficiency level of facilities during production. Cleaner Production Promotion Law (effective from January 1, 2003) and Circular Economy Promotion Law (effective from January 1, 2009) have initiated regulations on the efficient use of materials, and drive the IS companies to reduce, reuse and recycle the residue energy and material scraps. These Chinese companies have experienced legal pressures as they have to comply with these regulations. And Lopez-Gamero et al. (2010) believed that the regulatory pressures have positive impacts on proactive environmental practices. Based on discussions above, we have developed the following hypothesis:

Hypothesis 2-1. Regulatory pressures motivate the practices of CO_2 emission reduction in Chinese ISI.

Normative drivers derive “from external stakeholders who have interests in the organization” (Zhu and Geng, 2013). From this perspective, pressures from supply chains, customers and communities could have positive effect on iron & steel companies’ practices of CO_2 emission reduction. Similar results have been found by Zhang et al.(2008) who believes that environmental management practices of Chinese manufacturers is influenced by their suppliers and customers. It is shown that there are almost 60% of iron ores imported from foreign countries for Chinese ISI, 75.4% of which are monopolized by several suppliers (e.g. BHP Billiton, Vale of Brazil, Rio Tinto) in Australia, Brazil and India (Liao, 2011). Environmental preference from these suppliers can motivate IS companies to care about their environmental practices, such as energy conservation and emission reduction. In addition, customer requirement is a key normative pressure to implement environmental practices as well (Jørgensen et al., 2010). Many companies like Ford, GM and Toyota encouraged their Chinese suppliers to be certified with ISO 14001 standard. And some of these customers bring the cooperation on carbon trading or CDM project, which can provide motivation as well as capital and technology for ISI to promote its own CO_2 reduction practices. Based on the above discussion, the second hypothesis is forward:

Hypothesis 2-2. The pressures from supply chain motivate the practices of CO_2 emission reduction in Chinese ISI.

Mimetic effect refers to the tendency of individuals that inclined to imitate the successful practices of others around them. It is common for the companies to learn from the experiences in the industry so as not to lag behind their competitors or substitutions, including the environmental practices. With the increasing globalization, Chinese IS companies have gained more opportunities to learn from their leading international competitors in developed countries. Some environmental practices, such as the implementation of environmental management system, are introduced in some IS companies in China. These environmental practices of competitors can evolve as drivers for the practices of energy conservation and emission reduction (Zhu and Geng, 2010). Therefore, we have the following hypothesis:

Hypothesis 2-3. The environmental practices of competitors motivate the practices of CO_2 emission reduction in Chinese ISI.

The successful implementation of CO_2 emission reduction practices is based on the expenditure of various resources. Financial cost can be considered as a key barrier for the practices of CO_2 abatement. R&D of new technology for energy saving and carbon removal or storage often cost high investment, and cannot get clear benefit before application. And replacement of energy-intensive equipment and retrofit of industrial processes increase the short-term cost significantly. It is demonstrated by

Presley et al. (2007) that Chinese companies may hesitate to conduct the practices of energy-saving and CO_2 reduction since values may exist in non-financial ways such as improved image and better relationships with suppliers/customers. Moreover, lack of capacities is another barrier that hinders the practices of CO_2 abatement from the resource-based view. Human resource capability is an important resource for IS companies to implement CO_2 abatement practices. Lack of knowledge, skill and professional advice which are all supported by human resource, impose the restrict on the implementation of environmental practices (del Brio et al., 2008). Training of human resources, as a result, is an important stage for implementing environmental practices. Technology capacity is another resource for IS companies to implement CO_2 abatement practices. Many environmental practices come to an untimely end because of lacking advanced technology (Simonsson, 2002). The successful implementation of CO_2 abatement practices need smooth information collecting capacity as well. Information that are closely related to CO_2 emission reduction (e.g. information about climate change policies, development of advanced technology, carbon trading etc.), are a major concern for companies' decision making on the practices of CO_2 abatement. Lack of corresponding information would be a barrier for the CO_2 abatement practices of IS companies in China. Based on the above analysis, the following two hypotheses are posited:

Hypothesis 2-4. Financial cost impedes the practices of CO_2 emission reduction in Chinese ISI.

Hypothesis 2-5. Lack of capacities impedes the practices of CO_2 emission reduction in Chinese ISI.

From the perspective of individual companies, the implementation of CO_2 reduction practice aims finally to improve the performance of themselves. Without significant benefits, companies are unwilling to commit themselves to CO_2 abatement voluntarily. There are two kinds of performance concerned by the modern enterprises: environmental performance and economic performance, which are applied in our analysis.

Since environmental problems (e.g. climate change, pollution) have drawn great attention to the society, values from environmental performance start to attach more importance to the companies. The practices of reducing CO_2 emission would improve the social image of the company, and then could get more supports from the society and government. The relationship with customers or suppliers might be improved, especially during the international business. Less trading barriers related with carbon reduction would exist by virtue of the endeavor on CO_2 reduction practices. From the above analysis, we give the Sixth hypothesis:

Hypothesis 2-6. The practices of CO_2 emission reduction improve the environmental performance of IS companies.

The effects of CO_2 emission practices on companies' economic performance are a bit more complicated. On the one hand, the implementation of CO_2 emission reduction practice increased the operational cost of the company. It is required high investment on the technology innovation or the energy-efficient equipment retrofit. On the other hand, there would be great potential benefits from the CO_2 reduction practices. The reduced CO_2 emission could change into economic benefits during the trading on the international carbon market in the future. And the environmental fine or the carbon taxes would be reduced during the international business. Based on the above analysis, we give the seventh hypothesis:

Hypothesis 2-7. The practices of CO_2 emission reduction have an effect on the economic performance of Chinese IS companies.

2.4 Questionnaire survey for CER practices in IS industry

In this section, we describe the development of questionnaire and the process of data collection. Then we deduce the methodology that is used to verify various hypotheses.

(1) Questionnaire development

The questionnaire is covered by four sections: (1) CO_2 reduction practices; (2) The drivers and barriers; (3) Performance; and (4) Basic information. Measurement items in each section are developed based on the review of the literature, and then are organized to evaluate the theoretical framework as show in Fig.3. The four dimensions of CO_2 abatement practices are evaluated by 12 items which are referred to the previous studies (Zsidisin and Hendrick, 1998 [38]; Zhu et al., 2007). All the items are measured by using a five-point Likert-type scale (1-not considering it; 2-plan to consider it; 3- just implemented for less than one year; 4- implemented for 1~3 years; 5- implemented more than 3 years). There are 15 items to evaluate the 5 determinants that drive or hinder the implementation of CO_2 abatement practices in the second section of our questionnaire. These items are developed based on a previous study (Zhu and Geng, 2013). And questions for the items are measured by the agreement on the description with the five-point Likert-type scale (1- strongly disagree; 2- tend to disagree; 3- neither agree nor disagree; 4- tend to agree; and 5-strongly agree). Eight items in the third section of the questionnaire are developed with a focus on environmental performance and economic performance. These items are adopted from the experience of Zhu et al. (2010). Questions about company's performance improvement in recent 3 years are also answered using a five-point scale (1- none, 2-some but insignificant, 3- some but slightly significant, 4- significant, and 5- highly significant). To avoid the misunderstanding of the items in the whole questionnaire, we give a brief explanation at the beginning of each section.

In order to validate these measurement items, we first obtained comments from three academics in the field of environmental management. We required these experts to give their opinions on whether the items in the questionnaire are comprehensible according to the theoretical framework, and how to make further improvement. In the next step, we conducted a pilot test by distributing the manuscript of questionnaire to seven senior managers from IS companies who are taking charge of environmental management in their companies. They are asked to fill in the questionnaire and provide comments on the appropriateness of the questionnaire items and whether they are readily understandable by our target respondents in the ISI. Minor modifications on the wording of items are conducted during these processes of validating and pilot test.

(2) Data collection and sampling characteristics

This paper targeted the middle or senior level managers who are responsible for the environmental management in IS companies to fill in the questionnaire. The questionnaire distribution was conducted with the help of China Iron & Steel Association (CISA)[4]. It provided a list of 203 iron or steel companies who were registered in CISA. We sent the questionnaires to them by email, and the survey was undertaken over a period of five months. There were 96 responses that were finally received, but 11 of which were incomplete with many missing items. Therefore, the usable responses were 85, with an effective rate of 42.16%.

The description of sampling characteristics and distribution are displayed in Table 1. All the respondents are evenly distributed among the four kinds of ownerships and five different firm scales in terms of numbers of employees. Most of the respondents (58.8%) were from state-owned IS companies. This corresponds to the fact that this sector is dominated by state-owned enterprises (Guo and Fu, 2010). Since ISI in China is a labor intensive industry, 47% of the responses we collected are from the enterprises with employees above 10000.

Table 1. Profile of the respondent in ISI

Characteristics of respondents	Number	Percentage	Cumulative percentage
Ownership			
State-owned	50	58.8%	58.8%
Foreign enterprises	3	3.5%	62.3%
Joint ventures	5	5.9%	68.2%
Private Chinese enterprises	27	31.8%	100%
Total	85	100%	—
Number of employees			
<1000	4	4.7%	4.7%
1000-5000	22	25.9%	30.6%
5000-10000	19	22.4%	53.0%
10000-20000	15	17.6%	70.6%
>20000	25	29.4%	100%
Total	85	100%	—

To further verify the reliability of the responses, the test-retest method was conducted in this paper. A random sampling of 10% companies from the 85 responses was initiated. This is completed using the software SPSS 13.0. Managers who are in charge of environmental management in nine companies were interviewed using the

4 CISA was found in 1999, which is dedicated to providing service to steel producers and functioning its role as bridge, link, adviser and assistant.

questionnaire as a guide. We asked them to fill in the questionnaire again, and offer examples of CO_2 emission reduction practices and the difficulties that they faced. The interviews were undertaken during three months. Then a one-way analysis of variance (ANOVA) was performed between the previous responses and the interview responses. The results suggested that there were no significant differences between the answers of these two kinds of responses.

Appendix A shows the Cronbach's alpha values for each dimension in the questionnaire. The high values of Cronbach's alpha (>.70) suggest good internal consistency of the questionnaire (Nunnally and Bernstein, 1994). It is indicated that the reliability of all the items underlying CO_2 abatement practices, determinants and performance are reasonably well.

The factor analysis was introduced to test the construct validity of the questionnaire. We applied the maximum likelihood method with a varimax rotation to extract the theoretical factors. Both the screen test and initial eigenvalue test (eigenvalues>1) verified the four dimensions of CO_2 reduction practices, five dimensions of determinants and two dimensions of performance. The explanation power of the inherent variations reached to 84.61%, 81.21% and 72.26% respectively. The rotated component matrix is shown in Appendix A.

2.5 Empirical analysis for the relationships among determinants, practices and performance

In this section, we perform a regression analysis to examine if the determinants explored in section 3.1 are related to the CO_2 reduction practices, and in turn, if these practices have effects on the companies' performance. There are four regression models designed for examining the impact of five determinants (*regulatory policies*, *pressures from supply chain*, *imitating effect from competitors, financial cost* and *lack of capacity*) on the four CO_2 reduction practices (*CO_2 abatement innovation*, *residue recycling*, *CO_2 abatement strategy* and *implementation of carbon crediting mechanism*). Similarly, there is a second set of two separate regression models which each of the four CO_2 reduction practices are treated as dependent variable, while the two performance dimensions (*environmental performance* and *economic performance*) are defined as independent variables. We include company size as a control variable in each regression. This is due to the possibility that the size of the firm may influence the extent of their implementation of environmental practices (Zhu et al. 2007). As a result, nine total regressions are determined with the following functional forms:

CO_2 abatement practice $_{(N)}$ = F(Determinants, Organizational size, error) for (N=1~4) (1)

Performance $_{(M)}$ = F(CO_2 abatement practices, Organizational size, error) for (M=1~2) (2)

In the regression models, each factor for CO_2 abatement practices, determinants and performance are averaged from their underlying measurement items to form a single indicator factor. The summary factors were subsequently used for the regression analyses. The same processing method was also adopted by Zhu et al. (2007) , who indicated that such summary process can "reduce the model complexity and allow us to test the relationships based on small sample size".

(1) Descriptive statistic results

The mean values for the four dimensions of CO_2 reduction are shown in Table 2. There are relatively high commitments on CO_2 abatement strategy (3.53 for short-term objectives on energy saving or carbon abatement; 3.32 for long-term vision; 3.20 for clear plan). This means that in recent years, many IS companies have realized the importance of CO_2 reduction and consider it as an important assignment for their future development. For instance, *Wuhan Iron & Steel Group* has established series of strategic plans for energy conservation and emission reduction, such as *Plan for Energy Conservation and Dynamic Facilities, Plan for Construction of Circular Economy Style Company and Plan for Pro-environmental Production*. It plans to reduce 5% energy consumption per ton of steel from 2011 to 2015. The objective and performance of energy conservation and emission reduction are published in its annual *Social Responsibility Report*.

The innovations on energy-saving and CO_2 abatement get higher scores than average 3 as well. Many iron and steel companies in China implemented new technology on energy conservation in recent years, and replaced some backward facilities with energy efficient ones. For instance, *Baosteel* invested 4.02 billion CNY on 346 innovation projects for energy conservation and emission reduction from 2006 to 2010. However, all the standard deviations in this item are a bit high (all values over 1.00). This indicates that although some companies did well on their energy-saving and CO_2 abatement innovation, there are still some companies lag behind on it. From this point, there are still certain potential spaces for Chinese IS companies to continue their efforts on improving the energy efficiency, particularly in the backward IS industry.

However, the mean values for *Implementation of carbon crediting mechanism* are much lower, which are all below 2.5. This means that most Chinese IS companies in our questionnaire survey have not yet put carbon crediting mechanism into practice. This is due to the domestic underdeveloped carbon market[5] in China. There are few smooth channels for carbon trading and making economic benefits from carbon reduction, so that the companies are lack of enthusiasm to conduct carbon crediting mechanism to calculate their reduced carbon. But many of them have realized the inevitable trend of carbon trading and potential opportunity in carbon market, and planned to prepare for the carbon crediting mechanism. And some companies have gotten benefits from implementation of clean development mechanism (CDM). The relative large deviation value (over 1.00) of *Application of CDM* indicates that there are still several companies did well on the practice. A few Chinese IS companies have implemented CO_2 reduction projects with foreign investment and then sold credits of reduced carbon to the investors under the framework of CDM. For instance, *Jigang Group*[6] undertook a CDM project to reduce CO_2 emission by captive power

[5] Until now, there has been no compliance carbon market in China. Several voluntary carbon exchanges (e.g. Beijing Environmental Exchange, Shanghai Environmental Energy Exchange and Tianjin Climate Exchange) have been constructed while with small volume of business.

[6] *Jigang Group* is an iron & steel company located in Shandong province, China.

generation through waste heat recovery system. The corresponding amount of reductions reached 167,055 metric tonnes CO_2 equivalent per annum. And corresponding to our result, the score of *Construction of carbon reduction accounting system* is much low (mean value= 1.6, deviation value= 0.727). It indicates that Chinese IS companies still lack the administrative capacities for carbon trading. It appears that it will take some time for them to reach the criteria of MRV (measurable, reportable, verifiable) data. As a result, speeding up the process of domestic carbon market construction is a requisite way to arise IS companies' awareness of carbon crediting. Only providing a smooth channel for IS companies to exchange their reduced carbon credit with economic benefits, can they actually motivate to conduct carbon crediting mechanism and reduce carbon emission actively.

The mean values for the three items of residue recycling are between 2.5 and 3.0. It is indicated that the recycling of residual energy and waste materials is still under consideration or just implemented for a short time for many Chinese IS companies. And all the standard deviations are a bit high (all values over 1.00), which shows that different clusters of Chinese IS companies may exist due to different expression of residue recycling. There are several pioneering companies that initiate good practices on residue recycling. For instance, *Jigang Group* uses the recycled blast furnace gas, coke oven gas and converter gas to generate electricity power. There were 3.1 billion kWh electricity produced in 2010, which provided 52.3% of power use in *Jigang Group* and saved 0.27 Mt standard coal.

Almost all performance items are ranked higher to some degree, with mean values consistently within the 3.00 (3= to some degree) and 4.00 (4= relatively significant) ranges. This indicates that many companies think that they have improved certain performance on both environmental and economic perspectives in recent three years.

(2) Relationship between CO_2 reduction practices and corresponding determinants

The regression results for examining the impact of each determinant on the practices of CO_2 reduction are displayed in Table 3. Totally, the F-values in the four regression models are all high enough to reject the null hypotheses that the independent variables are not associated with the dependent variable. The hypotheses from one to five, at least, are verified partially. In order to check out the multi-collinearity of these regression models, variance inflation factor (VIF) was calculated checked among independent variables. The largest of the resulting VIF score in all of the regression models in Table 3 is 1.404, which is well below the maximum level of 10.0 suggested by Mason and Perreault (1991). This means multicollinearity should not be a serious concern in our regression.

For the impact on the CO_2 reduction practices of *Innovation*, pressures from supply chains impose a significant positive effect (β=0.191, P-value=0.062<0.1), while financial cost plays a negative role (β=-0.218, P-value=0.035<0.05). Hypothesis 2 and 4 are verified at this point. Innovation on energy conservation and CO_2 reduction needs high investment. For instance, the retrofit of equipment with energy efficient ones would increase constant cost the company. And the application of new technology on energy conservation and CO_2 reduction need high investment on R&D or substantive expenditure on purchasing. However, the benefits from energy conservation or CO_2 reduction are often not clear in the short-term (van Hemel and Cramer, 2002). As a result, few companies would like to afford high cost of innovation on energy conservation and CO_2 reduction without direct financial benefits. High cost becomes a barrier for the innovation practice. Contrarily, pressures from supply chains give a push to the practice of innovation on energy conservation and CO_2 reduction, although the effect is slightly significant. Many customers begin to care about the environmental ability of their suppliers, and require the product to be environmental friendly. For instance, Baosteel gets the certification of ISO 140001 in order to satisfy the requirements in the export market. In addition, suppliers (e.g. iron ore producers) raise the price in the name of environmental protection or CO_2 reduction, which force the IS companies retrofit their production process with energy conservation and CO_2 reduction. Therefore, more innovation activities would be implemented due to the higher pressures from both the demand and supply sides. Besides, the results also suggest that lager IS companies would more willing to implement innovation practices on energy conservation and CO_2 reduction. Larger companies have stronger capacities to afford the innovation cost.

There are only pressures from supply chains that have certain effect on residue recycling (β=-0.205, P-value =0.63 <0.1). It is indicated that the implementation of residue recycling is largely dependent on coordinating with the suppliers and customers. There need be smooth channels for the end-of-life product to be taken back from the customers to re-steel. And the residue energy and by-products need to find proper buyers to get the recycling moving on. For instance, the coke and oven gas are collected to the electricity supplier in some places of China. In addition, the insignificant effect of *Regulatory policies* on residue recycling could be understood. Until then, there seems no direct regulations that require IS companies to recycle their residue in China. Most IS companies recover the residues spontaneously in order to get economic benefits or improve their environmental performance. From this point, it could tentatively promote to the implementation of specific regulations or standards on residue recycling in IS industry. This would be helpful for motivate IS companies' residue recycling activities. However, the insignificant effect of *Financial cost* on *Residue recycling* is far beyond our expectation. We assumed that the financial cost would hinder the implementation of residue recycling since there might be high investment on the infrastructure or upgrading the equipments. But we neglect the economic benefits from the residue recycling. It would reduce the consumption of resource or energy, and might bring profits from the selling of recycled waste and by-product. These positive effects might neutralize the negative effects brought from financial cost. Moreover, we do not expect *Capacities* has no significant effect on *Residue recycling.* It indicates that most IS companies in China have the capacities (e.g. technology and talents) of residue recycling. Lack of capacities could not be a hinder for them to reuse and recycle the waste resource and by-products.

Table 2. Regression results between CO_2 reduction practices and corresponding determinants (standard estimations)

Independent variables	Dependent variables				VIF
	Innovation (t-value)	Residue recycling (t-value)	Implementation of carbon crediting system (t-value)	CO_2 reduction strategy (t-value)	
Firm size	.246 (2.413)*	.076 (0.693)	.305 (3.050)**	.197 (1.929)$^+$	1.134
Regulatory policies	.138 (1.218)	.037 (0.305)	-.041 (-.249)	.310 (2.727)**	1.404
Pressures from supply chains	.191 (1.895)$^+$	.205 (1.888)$^+$	.225 (2.267)*	.228(2.311)	1.114
Imitating effect	.147 (1.343)	-.183 (1.550)	.289 (2.707)*	-.070 (-.640)	1.310
Financial cost	-.218 (-2.152)*	-.009 (-0.084)	.216 (2.188)*	-.267 (-2.633)*	1.119
Capacities	-.139 (-1.322)	.163 (1.433)	-.265 (-2.579)*	-.036 (-.342)	1.212
Adjusted R squared	.232	.107	.269	.226	
F-value	5.227	2.686	6.144	5.088	

Note: ** $p < 0.01$; * $p < 0.05$; $^+$ $p < 0.1$

From Table 2, we can see that *Implementation of carbon crediting mechanism* is positively related to three determinants (namely *pressures from supply chains*, *imitating effect* and *financial cost*), and negatively related to *capacities*. From this point, hypothesis 2, 3 and 5 are verified. It is surprisingly to see that financial cost become a driver for the practice of *Implementation of carbon crediting mechanism*. For one thing, this might be somewhat attributed to the fact that the high investments of CDM projects are afford by the buyers of reduced CO_2. Financial cost, as a result, has insignificant negative effect on the implementation of CDM projects. For another thing, it is high cost to conduct carbon reduction for the energy-intensive IS companies. Carbon crediting mechanism provides an opportunity to buy carbon credits instead of reducing carbon emission themselves. In addition, our results also indicate that imitating effect play a significant role in *Implementation of carbon crediting mechanism* for Chinese IS companies. Some companies' attempts on carbon crediting mechanism would motive other companies' practices on it. In recent years, some IS companies in China have successfully conducted CDM projects, and get attractive benefits from them. Take *Wuhan Iron & Steel Group* for example, it benefits 204 million CNY from CDM annually. This would appeal other IS companies to apply for CDM. Our results show that pressures from supply chains are another traitor of *Implementation of carbon crediting mechanism*. Since a lot of businesses are happened in the global market for many Chinese IS companies, many of them realize the requisite trend of carbon trading in the future. In the contrast, lack of capacities hinders the Chinese IS companies to conduct carbon crediting as shown by our results. At present, few of the companies in China have the talents who are good at the rules and knowledge about carbon crediting mechanism or carbon trading. And the information about how to trading and how to benefit from the carbon market are in shortage. These barriers impose restrictions on the implementation of carbon crediting mechanism. Our results show that larger companies also seem to take advantage of carbon crediting mechanism. This might be due to their stronger capacities to get the information or cultivate the talents.

Regulatory policies has no significant influences on the practices of energy saving and CO_2 reduction except for the CO_2 reduction strategy. This indicates that the regulations of CO_2 emission in China are not sophisticated enough to have significant effect on detailed practices. However, it does give the directions for companies to face up to the CO_2 emission problems. Larger companies still have the advantage of strategy-making on energy conservation and CO_2 reduction. But the superiority is much smaller comparing with their implementation of innovation and carbon crediting.

(3) Relationship between CO_2 reduction practices and performance

Table 3 shows the regression results that examine the impact of CO_2 reduction practices on companies' performance. Hypothesis 6 is well supported since F-value reaches 10.674 that significantly pass through the verification of variance analysis. However, the F-value (F-value=3.063) for hypothesis 7 is a bit small, which indicates that the effect of CO_2 reduction on economic performance is less significant. Similar founding was proposed by Testa and Iraldo (2010) who thought that environmental practices in supply chain bring the significant environmental performance while the financial performance from such practices is still ambiguous. In addition, VIF for all independent variables in these two regressions ranges from 1.247 to 1.656, well bellowing the maximum level of 10.0. There are no problems of multi-collinearity in the two regressions as well.

Table 3. Regression results between CO_2 reduction practices and corresponding performance (standard estimations)

Independent variables	Dependent variables		VIF
	Environmental performance (t-value)	Economic performance (t-value)	
CO_2 reduction strategy	.308 (2.821)**	.084 (0.649)	1.580
Carbon trading	-.084 (-0.827)	.093 (0.771)	1.370
Residue recycling	.324 (3.322)**	.254 (2.200)*	1.256
Innovation	.207 (1.851)$^{+}$	.118 (0.893)	1.656
Firm size	.033(0.343)	-.040 (-0.344)	1.247
Adjusted R squared	0.365	0.109	
F-value	10.674	3.063	

Note: ** p < 0.01; * p < 0.05; $^{+}$ p < 0.1

Strategy of energy-saving and carbon reduction can be benefit for the environmental performance, while has no clear effect on the improvement economic performance. It is indicated that high environmental commitment could improve companies' environmental performance (e.g. emission reduction and energy conservation), but hardly bring direct economic benefits at least in the short-term. For instance, some strategic plans for energy conservation and emission reduction could improve companies' social image when they are published to the public. However, the corresponding benefits from these strategic plans would not come out until they are successfully implemented for several years.

Innovation on energy conservation and carbon emission appears to have positive effect on the environmental performance of company. Both replacing backward equipments with energy efficient ones and application of advanced technology for energy conservation could have direct effect on CO_2 reduction. However, its effect on economic performance is not clear. For one thing, while investment in innovation of energy conservation and carbon emission reduction is high, this increases the economic cost of the company. For another thing, the reduced emission of carbon or waste can bring indirect economic benefits, such as decrease the waste disposal fee and trading the reduced CO_2 through implementing CDM projects. As a result, the economic performance appears to be depended on the balance of innovation investment and benefits.

Residue recycling can bring both environmental and economic performance. On the one hand, the residue recycling practices can reduce the energy consumption and waste emissions, which will improve the companies' environmental performance. On the other hand, residue recycling can save cost of material and energy consumption. Furthermore, some recycled by-products or waste materials can be sold to other stakeholders for economic benefits. Take Baogang Group for example, there were 1.385 billion CNY expenditures saved on electricity power due to residue energy reuse and recycling from 2002 to 2009. Meanwhile, the discharge rate of blast-furnace gas dropped from 14.5% to 2.94% and the recycling rate of converter gas increase from 13.6% to 82.2%.

Our results show that there are no significant relationships between Implementation of carbon crediting mechanism and IS companies' performance (including both economic and environmental performance). This is likely due to the fact that carbon crediting mechanism has not been taken into practice for many IS companies in China. And carbon crediting is a long-term investment, significant benefits would not be appeared in short time.

Finally, firm size does not appear to be an important factor that influences the effect of CO_2 reduction practices of IS companies on their performance. This might be attributed to the fact that after several years eliminating poor productivity by the central government, many small and backward IS companies have been closed down. The reminders have certain capacities to improve their performance. This also indicates that the potential space for further eliminating poor productivity in ISI is getting smaller. The government needs to find other ways (e.g. market measures) instead of administrative intervention to reduce national carbon emission in future.

3. Inter-firm collaboration on carbon emission reduction within industrial chains

With the increasing concern on environmental problems, industrial firms begin to take a fresh look at the effects of their industrial supply chain management on the improvement of environmental performance. Inter-firm cooperation within industrial chain is one of the options for industrial firms to solve their environment problems. There are many different actions related to the inter-firm cooperation within industrial chains, such as eco-product design considering several phases of life cycle (Hugo and Pistikopoulos 2005), product recovery and remanufacturing including the participation of both suppliers and customers (Jayaraman 2006; Luo et al. 2001), reverse logistics which need the cooperation with customers (Sheu 2008) and closed-loop supply chain which requires all the participants on the industrial chain cooperating with each other (Barker and Zabinsky 2008). Some of these practices also have positive effects on carbon emission reduction. For instance, some energy-saving designs of the products are completed under the cooperation with customers (Zhu and Geng 2013).

3.1 The category of Inter-firm collaboration on CER within industrial chains

This paper is to investigate inter-firm cooperation on carbon emission reduction within industrial chains. According to the differences of cooperation partners, we classified the inter-firm cooperation into three categories:

(1) From the perspective of vertical extended industrial chain, industrial firms could cooperate with their suppliers and customers on carbon emission reduction. Cooperation with customers or suppliers for using less energy during product transportation is a representative example of this kind of cooperation on carbon emission. Recovery of waste energy and product from the customers could not only reduce the cost of purchasing materials, but also save the energy from waste energy reuse and decrease the energy consumption in producing the saved materials. And these recovery practices need the cooperation with customers and suppliers. Moreover, the design of energy saving products would also consider the demand of customers and supply capacity of the suppliers. The cooperation with customers and supplies, as a result, become an effective way to improve products' energy efficiency. Other cooperation practices with suppliers and customers such as green packaging and cleaner production would also have indirect positive effects on carbon emission reduction.

(2) From the point of view of horizontal expanded industrial chain, it is another option for industrial firms to cooperate with their competitors and surrogates. As it is known, there are some similarities on industrial technology and process between industrial firms and their competitors or surrogates. And carbon emission problems, most of the time, are the common problems of industrial competitors and producers of

substitute, since they belong to the same industry and face similar environmental pressures. Therefore, there are common ground for industrial firms to cooperate with their competitors and surrogates on carbon emission reduction. Besides, the R&D investment on energy efficiency and carbon emission reduction would be a big burden for most industrial firms. The cost could be shared by means of cooperation with competitors who have similar technology demand.

(3) From the perspective of industrial symbiosis, industrial firms in different industrial chains can cooperate with each other by the waste energy and resource exchange. Industrial symbiosis gives a platform for industrial firms to exchange their waste resources with other firms, who in most situations have no direct "supply-demand" relationship with them. This kind of cooperation among several industrial chains based on industrial symbiosis, most of the time, combines the effects of carbon emission reduction. Hashimoto et al. (2010) analyzed the CO_2 emission reduction through industrial symbiosis for cement firms cooperating with other firms such as iron & steel firms and power plants. This provides a new option for industrial firms to reduce carbon emission through the cooperation with the firms in other industrial chain.

Above all, the framework of inter-firm cooperation on carbon emission reduction through industrial chains can be described as Figure.4. This framework concludes the paths for industrial firms to reduce their carbon emission by cooperation within industrial chains.

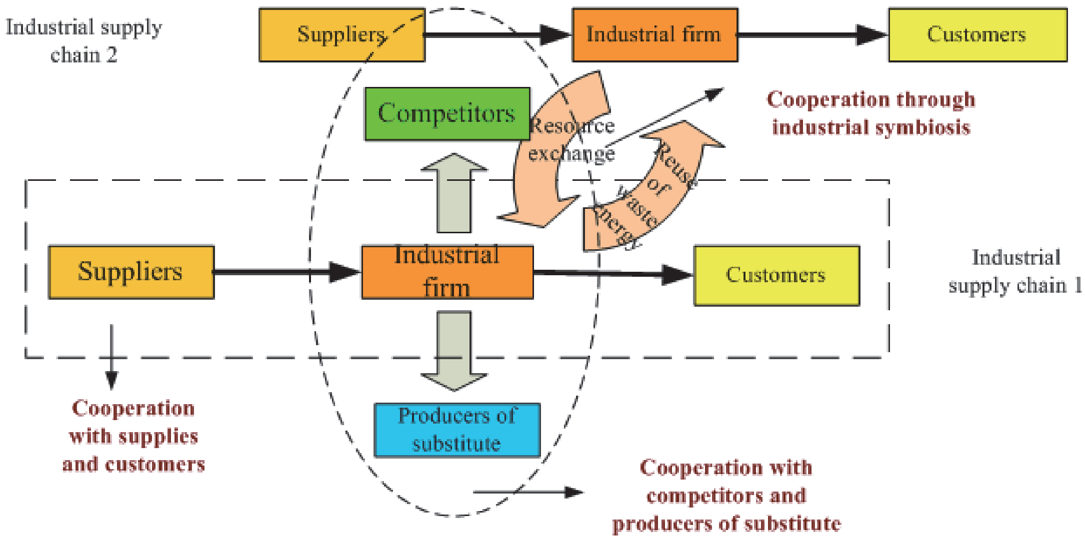


Fig. 4. The framework of inter-firm cooperation on carbon emission reduction

3.2 Theoretical model for the willingness and motivation of inter-firm collaboration on CER

Figure 4 describes three kinds of inter-firm cooperation on carbon emission within industrial chains. However, it is not clear what are the drivers or barriers that influence the implementation of each kind of inter-firm cooperation. And does the inter-firm cooperation within industrial chain have any effects on the improvement of industrial firms' performance? This part gives a theoretical model to solve these problems.

Institutional theory is widely used in identifying the external determinants for environmental management practices (e.g. Zhu and Geng 2013; Prajogo et al. 2012; Zhu et al. 2012). DiMaggio and Powell (1983) pointed out that the environmental practices can be driven by three kinds of institutional factors: coercive, normative and mimetic. Inter-firm cooperation on carbon emission reduction is a representative environmental practice, which as a result, can also identify its external determinants from the view of institutional theory.

Coercive driver comes from the compulsive pressure exerted by powerful agencies such as the government (Rivera 2004). Environmental regulation is often considered as the coercive pressure, and its effect on motivating the environmental practices of the firms has been verified by many scholars (e.g. Jones 2010; Lopez-Gamero et al. 2010). Zhang and Cheng (2009) verified that the government of China can purse carbon emissions reduction policy in the long run without impeding economic growth. Correspondingly, Chinese government has promulgated series of laws and decrees to regulate the industrial firms' production process on energy use and carbon emission, such as Energy Conservation Law (first effective in 1997 and amended in 2007) and Circular Economy Promotion Law (effective from January 1, 2009). Many of these regulations promote the industrial firms to find more ways to deal with their carbon emission problems. Specially, when the industrial firms' single carbon emission reduction practice has limited effect, they have to rely on cooperation with each other on carbon emission reduction. From the above analysis, we give the first hypothesis:

Hypothesis 3-1. Environmental regulations motivate inter-firm cooperation on carbon emission reduction within industrial chain.

Normative refers to the influence from external stakeholders who have business relation with the organization. From the perspective of industrial chain, suppliers and customers, even the competitors can be considered as the stakeholders who can influence the industrial firms' environmental behavior (Yin and Ma 2009; Jørgensen et al. 2010). For one thing, the demand of carbon emission reduction for these stakeholders on the industrial chain is the prerequisite of inter-firm cooperation. Only when both the industrial firms and their stakeholders (e.g. suppliers, customers or the competitors) need to reduce carbon emission, are there any chances for them to cooperate with each other on carbon emission reduction. For another, the requirements of carbon reduction from customers and suppliers are also key drivers for industrial firms to implement environmental practices (Zhang et al. 2008), such as inter-firm cooperation on carbon reduction. Based on the above discussion, the second hypothesis is as follows:

Hypothesis 3-2. Carbon emission reduction demand from stakeholders motivates inter-firm cooperation on carbon emission reduction within industrial chain.

Mimetic refers to the imitating effect that the individuals tend to learn from the successful practices of other individuals. The imitating effect is also reflected in the implementation of environmental practices (Prajogo et al. 2012). The good performance of some industrial firms' environmental practices often motivates other firms to imitate. Inter-firm cooperation on carbon emission reduction also needs several successful cooperation cases to demonstrate the advantage and possibility of cooperating with other stakeholders within the industrial chains on carbon reduction. As a result, other industrial firms can be attracted to imitate these successful experiences and participate in the inter-firm cooperation on carbon emission reduction. Then we have the following hypothesis:

Hypothesis 3-3. Imitating effect motivates inter-firm cooperation on carbon emission reduction within industrial chain.

The internal determinants for industrial firms to implement environmental practices are often identified from the resource based view (e.g. Zhu & Geng 2013; Prajogo et al. 2012). It was verified that lack of resource and capacity are the main barriers for environmental practices (Ebinger et al., 2006). This paper also identified the internal determinants of inter-firm cooperation on carbon reduction from the resource based view.

Financial factors such as short-term cost burden (Sarkis et al. 1997) and unclear benefits (van Hemel and Cramer 2002) are the important determinants for implementation of environmental practices. However, the effects of financial pressures on inter-firm cooperation on carbon emission reduction are a bit more complicated. On the one hand, the cooperation increases the operating cost of industrial firms, which impedes the implementation of inter-firm cooperation on carbon emission reduction. On the other hand, the increasing carbon reduction cost forces the industrial firms to cooperate with each other to share the heave financial burden of carbon reduction. From this perspective, financial pressures play a positive role in motivating inter-firm cooperation on carbon emission reduction. From the above analysis, the following hypotheses are given:

Hypothesis 3-4. Financial pressures motivate inter-firm cooperation on carbon emission reduction within industrial chain.

Defective infrastructure and mechanism is a big problem that influences the inter-firm cooperation. Lopéz (2008) pointed out that the mechanism of cost-risk sharing is the key factor for the successful cooperation. It is more complicated to design the cost-risk sharing mechanism for inter-firm cooperation on carbon reduction, since its variety patterns of cooperative practices. Trust is another important factor that determines the success of cooperation (Okamuro 2007). Industrial firms prefer to cooperate with trusted participants on carbon reduction, especially those they are familiar with or have cooperative experience beforehand. The trust mechanism can reduce the risk of opportunistic behavior such as the "free riders", which could be quite common during the inter-firm cooperation on carbon reduction. Defective safety mechanism also impedes the implementation of inter-firm cooperation on carbon emission. Some industrial firms worry about the leakage of their key information during the cooperation. Thus, the fifth hypothesis is put forward:

Hypothesis 3-5. Defective infrastructure and mechanism impedes inter-firm cooperation on carbon emission reduction within industrial chain.

3.3 Questionnaire survey on the CER inter-firm collaboration within energy intensive industries in China

To verify the hypotheses developed in section 3, we designed a questionnaire survey to investigate the inter-firm cooperation on carbon emission. The processes of questionnaire development and data collection are described in this section.

(1) Questionnaire development

Four sections are designed to constitute the questionnaire: (1) Inter-firm cooperation on carbon emission reduction; (2) Determinants; (3) Performance; and (4) Basic information (see in Appendix A). The measurement structure is organized as the conceptual model shown in Figure 2. The measurement items in each section are developed on the basis of the previous studies. There are five measurement items in the section of Inter-firm cooperation on carbon emission reduction. Three measurement items are to evaluate the carbon reduction cooperation with suppliers and customers, which refers to Zhu et al. (2007), Carter RC & Carter JR (1998) and Chan & Lau (2001). One measurement item is designed to evaluate the carbon reduction cooperation with competitors and surrogates, which refers to Poyago-Theotoky (2007). And the last measurement item is for the cooperation based on industrial symbiosis, which refers to the study of Zhu & Geng (2013). This is because there are various patterns of cooperation with suppliers and customers, such as the cooperation on eco-design, energy-saving transportation and waste product recovery. Contrarily, the other two kinds of cooperation are simple. All the items in this section are measured according to the implementation experience of the cooperation, by using a five-point Likert-type scale (1-not considering it; 2- plan to consider it; 3- just implemented for less than one year; 4- implemented for 1~3 years; 5- implemented more than 3 years).

There are 15 measurement items to evaluate the determinants in the second section of the questionnaire. Each determinant is in respond to three measurement items. The three items of *Regulation* are learned from Zhu et al. (2007). The dimension of *Carbon emission reduction demand from stakeholders within industrial chain* is evaluated referring to the studies of Jørgensen et al. (2010), Yin & Ma (2009) and Zhu et al. (2007). The items of Imitating *effect* are designed referring to Zhu & Geng (2013), Prajogo et al. (2012). The items for evaluating *Financial pressure* are developed by developed on the previous studies (Sarkis et al. 1997; van Hemel and Cramer 2002; Zhang et al. 2012). And Defective infrastructure and mechanism is measured by three items referring to Okamuro (2007), Lopéz (2008), Bonte (2008). Questions for these items are answered by the agreement on the items' description with the five-point Likert-type scale (1- strongly disagree; 2- tend to disagree; 3- neither agree nor disagree; 4- tend to agree; and 5- strongly agree).

8 measurement items are designed in the third section of Performance: 4 items for evaluating environmental performance and 4 items for economic performance. These

items are designed mainly referring the experience of Zhu et al. (2010). Questions for each item are developed by asking firms' performance improvement in recent 3 years, which are also answered using a five-point scale (1- none, 2-some but insignificant, 3- some but slightly significant, 4- significant, and 5- highly significant). A brief explanation at the beginning of each section was given to avoid the misunderstanding of the items.

In order to validate the measurement structure of the questionnaire, we gave a pilot test by distributing the questionnaire draft to 10 senior managers who are in charge of environmental management issues from industrial firms in China. We ask them to complete the questionnaire and provide comments on the understandable of the questionnaire items and how to make further improvement. Minor modifications on the wording of items are conducted during the pilot test.

(2) Data collection and sampling characteristics

Energy intensive industrial firms are targeted as the source of data collection in this paper. These industries were selected because they have relatively high levels of energy consumption and carbon emission. Energy intensive industries are characterized by high energy to output ratios. They are the industries which have large amounts of energy consumption but relatively low value output (Puran Mongia et al 2001). Accordingly, six industries are chosen out of 37 identified sectors according to the criterion that the total primary energy consumption are over 100 million tons SCE[7] and energy consumption out of the output value are more than 50 thousand tons SCE / billion RMB. They are Petroleum Processing and Coking (PPC), Smelting and Pressing of Nonferrous Metals (SPNM), Smelting and Pressing of Ferrous Metals (SPFM), Raw Chemical Materials and Chemical Products (RCMCP), Electric Power, Steam and Hot Water (PSEP) and Nonmetal Mineral Products (NMP), as shown in Figure 5.

We employed questionnaire surveys of the above six kinds of energy intensive firms in China. In order to reflect the distribution of these industries in China, we chose four major cities concentrated with energy intensive industries as our targeted research areas. They are Shijiazhuang of Hebei Province in Northeast China, Wuhan of Hubei Province in Middle China, Taiyuan of Shanxi Province in North China, and Guangdong of Guangzhou Province in Southeast China. These regions represent some kinds of the most energy intensive and industrially concentrated areas in China.

[7] SCE is unit of energy, which is short for standard coal equivalent

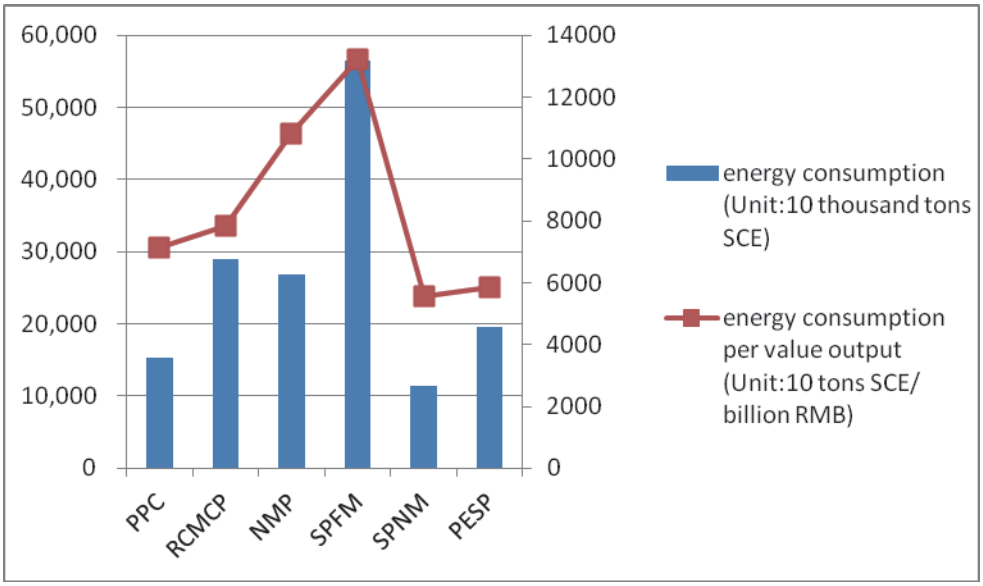


Fig. 5. Energy intensive industries: some indicators[8]

The whole survey was undertaken over a period of 4 months. Out of a total of 693 questionnaires distributed to representatives, a total of 258 usable responses from energy intensive industrial firms were collected. All respondents had middle or senior management experience. They often have board knowledge about the firms' daily operation, and were also targeted as the respondents by some similar studies (e.g., Carter et al., 1998; Zhu et al., 2012).

Table 4. Profile of the respondents participating in the survey

Characteristics of respondents	Number	Percentage	Cumulative percentage
Number of employees			
<100	41	15.9%	15.9%
100-500	64	24.8%	40.7%
500-1000	43	16.7%	57.4%
1000-3000	65	25.2%	82.6%
>3000	45	17.4%	100%
Total	258	100%	—
Industrial type			
PPC & RCMCP[9]	79	30.6%	30.6%
PSEP	23	8.9%	39.5%
NMP	47	18.2%	57.8%
SPFM	60	23.3%	81.0%
SPNM	49	19.0%	100%
Total	258	100%	

Table 4 shows the description of respondent firms in terms of industrial type and firm size using employment levels. Firm size of industrial firms is often characterized by the number of full-time employees (Dean & Snell 1991). Firm size of the

[8] Data source: "National Statistical Yearbook on industry and energy (2009)"
[9] PPC and RCMCP have strong industrial relationship with each other. Many firms of the respondents involved in both the two industrial business. Therefore we combine the two industries as one type.

respondents ranged from under 100 to over 3000 employees with the majority of firms falling into middle-sized firms classified between 500 and 3000 employees. These five types of industries represent the energy intensive consumers and heavy carbon emitters.

(3) Reliability and validity test

To further verify the reliability of the responses, Cronbach's alpha coefficients and item-total correlations are introduced in this paper. As shown in Table 2, the majority of Cronbach's alpha coefficients of measurement items are above 0.90, and the lowest one reaches 0.889. The threshold value of reliability was recommended above 0.70 by Nunnally & Bernstein (1994). This suggests good internal consistency of the questionnaire. Besides, the item-total correlations of all measurement items are at a high level (above 0.70), which suggest that each item has close correlation to their corresponding higher level constructs. Moreover, we calculated the Cronbach's alpha coefficients of corresponding higher level constructs after deleting the item. Most of the values decreased compared with the Cronbach's alpha coefficients before deleting the items. This further indicates good reliability of the questionnaire. Although the Cronbach's alpha coefficients increased after deleting the three items (L3, M3, J1), the increased the values are too minor to be considered. And the previous Cronbach's alpha coefficients are high, we still confirmed the three items reliability in the measurement structure.

The confirmatory factor analysis (CFA) was introduced to test the construction validity of the questionnaire. Firstly the factors were extracted using the orthogonal rotation. The results were shown in the left part of Figure 6. It was shown that the estimated standard coefficients of each item are all above 0.8, which suggests good measurement structure. However, some fitting indices are not as good as the estimated standard coefficients, seen in Table 5. Rooted mean square error of approximation (RMSEA) is 0.083, which is a bit lower than the good fitting criterion of below 0.08 suggested by Steiger (1990). Goodness-of-fitting index (GFI) is 0.88, which does not reach the threshold of 0.90 suggested by Huang (2005) as well.

Modification indices (MI) suggest that there are certain co-variation relation between the factor *Regulation* and *Carbon emission reduction demand from stakeholders within industrial chains*. In order to verify this relationship, we conducted another CFA using oblique rotation. The results were shown in the right part of Figure 6. It was shown that the estimated standard coefficient between the two factors is 0.43, which means there are certain relations between the two factors but not too mush important. However, the fitting indices after the modified CFA become much better. Both the RMSEA and GFI pass the threshold of the criterion, as seen in Table 6. It is understandable to explain the co-variation relation between the two factors, since regulation could play a positive role in forcing the other stakeholders within supply chain to address their carbon emission problems.

Table 5. Reliability test and descriptive statistics

Factors	Items	Item-total correlations	Cronbach's alpha after deleting the item	Cronbach's alpha
Regulation (REG)				0.960
	L1	0.929	0.931	
	L2	0.944	0.918	
	L3	0.876	0.970	
Carbon emission reduction demand from stakeholders within industrial chains (CDI)				0.889
	I1	0.773	0.854	
	I2	0.780	0.850	
	I3	0.806	0.822	
Imitating effect (IE)				0.932
	M1	0.872	0.892	
	M2	0.898	0.871	
	M3	0.813	0.938	
Financial pressure (FP)				0.910
	E1	0.781	0.903	
	E2	0.882	0.817	
	E3	0.802	0.886	
Defective infrastructure and mechanism (DIM)				0.967
	J1	0.901	0.970	
	J2	0.954	0.931	
	J3	0.929	0.950	
Environmental performance (EP)				0.908
	EP1	0.795	0.881	
	EP2	0.850	0.860	
	EP3	0.815	0.873	
	EP4	0.716	0.907	
Economic performance				0.907
	CP1	0.783	0.881	
	CP2	0.868	0.855	
	CP3	0.743	0.898	
	CP4	0.777	0.883	

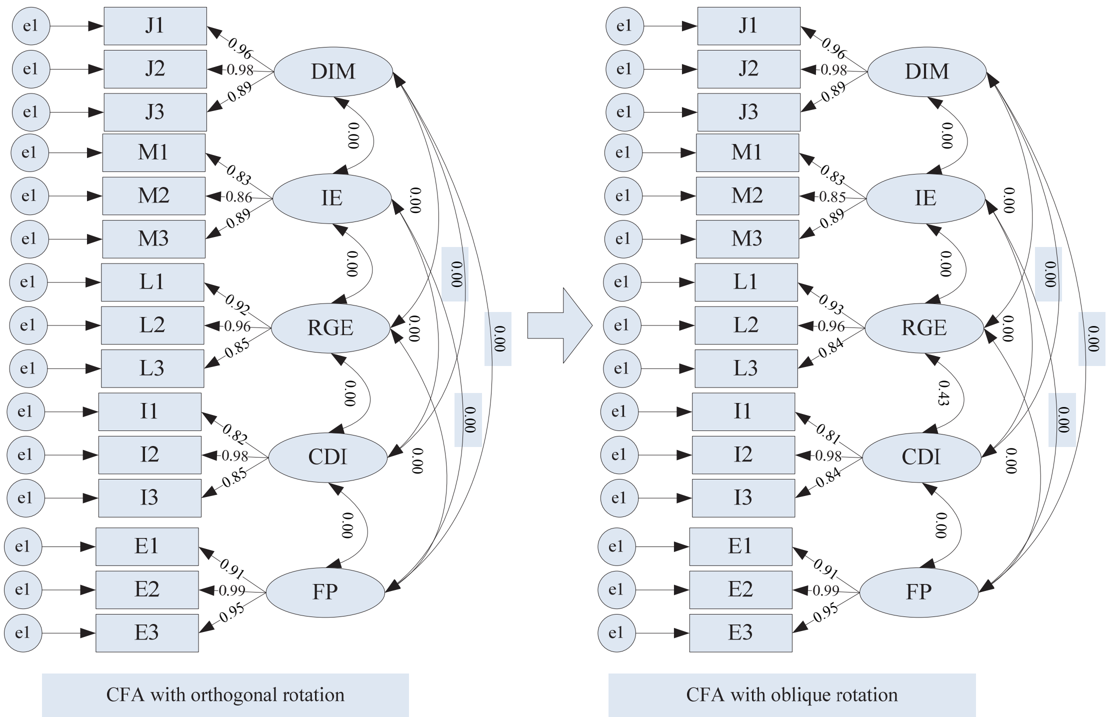


Fig. 6. CFA results with orthogonal rotation and oblique rotation

Table 6. The fitting indices of CFA

			Fitting indices					
	χ^2	df	χ^2/df	RMSEA	GFI	NFI	CFI	IFI
Criterion			<5	<0.08	>0.9	>0.9	>0.9	>0.9
CFA with orthogonal rotation	250.31	90	2.781	0.083	0.88	0.935	0.957	0.958
CFA with oblique rotation	203.408	89	2.285	0.071	0.90	0.947	0.970	0.970

The Chi-square values in both two CFA model are a bit high, however, the Normed Chi-square indices (χ^2/df) are low enough to fit criterion of below 5 suggested by Hou et al. (2004). Above all, we confirm the acceptable validity of the questionnaire structure.

3.4 Methodology for the motivation of inter-firm collaboration on CER

After the data collection by the survey, we used Multiple Linear Regression (MLR), Binary Choice Model (BCM) and Ordinal Choice Regression (OCR) to analyze three kinds of inter-firm cooperation on carbon emission respectively.

(1) MLR for determinants of carbon reduction cooperation with suppliers and consumers

There are three measurement items for evaluating cooperation with suppliers and consumers on carbon reduction. Factor analysis was introduced to validate the measurement construction using the principal component methods. Table 7 shows the factor matrix with a varimax rotation. One theoretical factor was extracted using the Kaiser criterion (eigenvalues>1), with the explanation power of the inherent variations reaching to 70.912%. Cronbach's alpha reaches 0.789, which confirms the reliability of the factor.

Table 7. The factor matrix on cooperation with suppliers and consumers on carbon reduction

		Component
		1
Cooperation with suppliers and	ZC_1	0.856
consumers on carbon reduction	ZC_2	0.903
(Cronbach's alpha=0.789)	ZC_3	0.761

We used the multiple linear regression to discuss the relationship between cooperation with suppliers and consumers on carbon reduction and its determinants. The dependent variable is from the calculation of factor score in the above factor analysis, seen as follows:

$$ZC_i = \varpi_1 ZC_{1i} + \varpi_2 ZC_{2i} + \varpi_3 ZC_{3i} \quad (1)$$

Where ZC_i refers to the score of cooperation with suppliers and consumers on carbon reduction for the No. i response. ϖ_j refers to the loading coefficients for NO. j item on the factor ZC .

The following functional form is the MLR in this paper:

$$ZC = \beta_0 + \beta_1 REG + \beta_2 CDI + \beta_3 IE + \beta_4 FP + \beta_5 DIM + \beta_6 control + \varepsilon \quad (2)$$

Where each determinant (REG, CDI, IE, FP, DIM) identified in Section 2 is also evaluated by factor score through the EFA to form a single indicator factor. Firm size and industrial type are used as the control variables, and industrial type is introduced in the format of dummy variable. $\beta_0 - \beta_6$ are the estimated coefficients of this model; ε is regression error term.

(2) BCM for determinants of carbon reduction cooperation with competitors and surrogates

From the distribution of the variable HC, most scores are below 3 or at 3. This means most firms either have not implemented carbon reduction cooperation with competitors or surrogates (below 3), or just conducted the cooperation within a year (at 3). Only a few responses get the score at 4 or 5, which means carbon reduction cooperation with competitors or surrogates has been implemented for more than 2 years. As a result, we transformed the score structure into a "0-1" model. The scores below 3 are transferred to 0, which means the firm did not conduct carbon reduction cooperation with competitors or surrogates. And the scores above 2 are transferred to 1, which means the firm has conducted conduct carbon reduction cooperation

Then a binary choice model (BCM) was introduced to discuss the determinants for carbon reduction cooperation with competitors or surrogates. The following specification was used:

$$HC^* = \beta_0^{hc} + \beta_1^{hc}REG + \beta_2^{hc}CDI + \beta_3^{hc}IE + \beta_4^{hc}FP + \beta_5^{hc}DIM + \beta_6^{hc}control + \varepsilon^{hc} \quad (3)$$

$$P(HC = 1) = 1 - F(\text{-HC}^*) \quad (4)$$

$$s.t. \quad 0 \le \mathrm{P}(HC_i = 1 | \mathrm{x_i}) \le 1, \ \mathrm{x_i} = \mathrm{RGE}, CDI, IE, FP, DIM \quad (5)$$

Where HC^* is latent and continuous measure of carbon reduction cooperation with competitors or surrogates; HC is the observed variable of carbon reduction cooperation with competitors or surrogates; β^{hc} is a vector of parameters to be estimated; ε^{hc} is a random error term. F is the probability distribution function assumed proactively; P is the possibility value between 0 and 1.

(3) OCR for determinants of carbon reduction cooperation based on industrial symbiosis

The observed variable of IS is characterized by how long have carbon reduction cooperation based on industrial symbiosis been implemented. Five tiers from 1 to 5 have been given to evaluate the implementation. As a result, ordinal choice regression (OCR) was introduced to discuss the determinants of carbon reduction cooperation based on industrial symbiosis. The following specifications were used:

$$IS^* = \beta_0^{is} + \beta_1^{is}REG + \beta_2^{is}CDI + \beta_3^{is}IE + \beta_4^{is}FP + \beta_5^{is}DIM + \beta_6^{is}control + \varepsilon^{is} \quad (6)$$

$$IS = \begin{cases} 1, & IS^* \le c_1 \\ 2, & c_1 < IS^* \le c_2 \\ 3, & c_2 < IS^* \le c_3 \\ 4, & c_3 < IS^* \le c_4 \\ 5 & c_4 < IS^* \end{cases} \quad (7)$$

$$\begin{gathered} P(IS = 0) = F(c_1 - IS^*) \\ P(IS = 1) = F(c_2 - IS^*) - F(c_1 - IS^*) \\ P(IS = 2) = F(c_3 - IS^*) - F(c_2 - IS^*) \\ P(IS = 4) = F(c_4 - IS^*) - F(c_3 - IS^*) \\ P(IS = 5) = 1 - F(c_4 - IS^*) \end{gathered} \quad (8)$$

Where IS^* is latent and continuous measure of carbon reduction cooperation with competitors or surrogates; IS is the observed variable of carbon reduction cooperation with competitors or surrogates; β^{is} is a vector of parameters to be estimated; c is a vector of unobserved threshold value; ε^{is} is a random error term. F is the probability distribution function assumed proactively.

3.5 Empirical results for the motivation of inter-firm collaboration on CER

Table 8 shows the descriptive results of carbon reduction cooperation based on industrial chains. From the mean values at the bottom of the table, we can see that all kinds of carbon reduction cooperation do not get high scores. Carbon reduction cooperation on R&D with competitors or surrogates gets the lowest score 2.62, which means most industrial firms have just realize the possibility of this kind of cooperation. The score of carbon reduction cooperation based on industrial symbiosis is 3.04, relatively higher than other two kinds of cooperation. This means there are elementary experiences for many industrial firms to cooperate through industrial symbiosis. For carbon reduction cooperation with suppliers and customers, the three kinds of measurement items get similar scores around 3. Cooperation on energy-saving transportation gets the highest score since it is easier to implement by industrial firms. While low-carbon design cooperation is complicated to implement, so that it gets a relative lower score. The values of Std. Deviation for all carbon reduction cooperation items are above 1.00, which indicates that the performance of carbon reduction cooperation for each individual industrial firms are quite different. There are several pioneering firms that initiate good practices on carbon reduction cooperation, but also some backward firms unwilling to participate in the carbon reduction cooperation.

Panel A describes the description of carbon reduction cooperation in different firm sizes. Pearson Chi-Square shows that industrial firms in different firm sizes have significantly different performances on carbon cooperation through industrial symbiosis and carbon reduction R&D cooperation with competitors or surrogates. For carbon reduction cooperation with customers and suppliers, only the performances of cooperation on waste product recycling are different according to the firm size. Other two practices are not influenced by firm size.

Panel B gives the descriptive statistics of carbon reduction cooperation in different industrial types. Pearson Chi-Square shows that the performances for all carbon reduction cooperation types are different in the different industries. The performances of carbon reduction cooperation in NMP and SPFN are better than other industries, while SPNM gets the lowest score.

Table 8. Descriptive results of carbon reduction cooperation based on industrial chains

		ZC1		ZC2		ZC3		IS		HC	
	NO.	Mean	Mode	Mean	Mode	Mean	Mode	Mean	Mode	Mean	Mode
Panel A											
Firm size=1	79	3.03	2、4	3.24	4	3.14	4	3.25	5	2.86	3
Firm size=2	23	3.04	4	2.87	2	2.96	1、5	3.35	3	3.04	3
Firm size=3	47	2.60	2	2.87	4	2.98	4	3.17	5	2.66	2、3
Firm size=4	60	3.05	4	3.25	4	3.23	4	3.2	5	2.68	3
Firm size=5	49	2.63	3	2.77	4	2.22	1	2.22	2	1.92	1
Pearson Chi-Square		16.389		13.744		29.407**		41.064**		39.486**	
Panel B											
PPC& RCMCP	41	2.41	3	2.78	1	2.41	1	3.02	5	2.61	3
PSEP	64	3.02	2	3.25	4	3.30	4	3	5	2.56	3
NMP	43	2.88	2	3.44	4	3.30	4	3.88	5	3.23	3
SPFM	65	3.34	4	3.18	2	3.06	4	3.15	4	2.71	3
SPNM	45	2.44	1	2.47	1	2.4	1	2.13	1	2	1
Pearson Chi-Square		70.557***		60.336***		47.185***		75.497***		45.025***	
Mean		2.88		3.05		2.94		3.04		2.62	
Std.Deviation		1.26		1.38		1.45		1.58		1.24	

Note: *** $p < 0.01$; ** $p < 0.05$

(1) Determinants of carbon reduction cooperation with suppliers and consumers

Table 9 shows the regression results of determinants' effects on carbon reduction cooperation with suppliers and consumers. Variance inflation factors (VIF) were calculated to check multi-collinearity among independent variables. The largest VIF score in all of the regression models in Table 8 is 2.495, which passes the threshold of below 10.0 suggested by Mason and Perreault (1991). In order to avoid the heteroscedasticity during the regression, ordinary least squares method after white robust standard deviation correction was used by using EVIEWS 6.0. Model 1 was only introduced firm size as the control variable. Model 2 considered both firm size and industrial type as the control variables. Model 3 was to verify the interaction effect between REG and CDI on carbon reduction cooperation with suppliers and consumers. And the F-values of the three models are all high enough to reject the null hypotheses that the independent variables are not associated with the dependent variable.

All the three models show that carbon reduction demand from the stakeholders in the supply chain is the main driver for carbon reduction cooperation with suppliers and consumers. If the carbon reduction pressures of the suppliers and consumers are strong, the industrial firms are more easily to get into carbon reduction cooperation with them. Financial pressure is the significant determinants to impede the carbon reduction cooperation with suppliers and consumers. The cooperation might increase the operation cost of the firms, which make them unwilling to cooperate with each other. The defective infrastructure and mechanism also plays a negative role in carbon reduction cooperation with suppliers and consumers. Due to the newly realization of carbon reduction cooperation with suppliers and consumers, firms do not dare to try this kind of cooperation until there are some mature and trusty mechanisms. However, the imitating effect does not come into work since the successful cases of carbon reduction cooperation are still at a low level.

Table 9. MLR results for determinants of carbon reduction cooperation with suppliers and consumers

	Regression results			Model 1	Model 2	Model 3
	Model 1	Model 2	Model 3	VIF	VIF	VIF
REG	-0.017 (-0.197)	-0.023 (-0.272)		1.192	1.063	
CDI	0.219*** (3.170)	0.233*** (3.410)	0.239* (1.800)	1.025	1.058	1.058
IE	0.126 (1.501)	-0.112 (1.362)	-0.110 (-1.348)	1.136	1.327	2.560
FP	-0.144** (-2.107)	-0.154** (-2.357)	-0.158** (-2.419)	1.147	1.152	1.152
DIM	-0.116*** (-2.935)	-0.121** (-3.030)	-0.120** (-3.023)	1.033	1.052	1.050
REG*CDI			-0.002 (-0.105)		2.495	2.495
Firm size	-0.016 (-0.324)	-0.034 (-0.720)	-0.034 (-0.704)	1.041	1.203	1.064
PPC& RCMCP		0.491*** (3.022)	0.490*** (3.028)		1.864	1.864
PSEP		0.454* (1.651)	0.453 (1.648)		1.358	1.358
NMP		0.113 (0.587)	0.110 (0.575)		1.663	1.662
SPFM		0.538*** (3.824)	0.535*** (3.091)		1.778	1.778
β_0	-0.382 (-0.750)	-0.575 (-1.165)	-0.636 (-1.264)			
F statistic	4.270***	4.030***	4.020***			
R^2 statistic	0.093	0.140	0.140			

Note:① *** p < 0.01; ** p < 0.05; * p < 0.1; ② the data at the upside of the cell is the standard coefficient; the data at the bottom of cell is the t statistic value after robust standard error modifying

From Model 2, we can see the performance of carbon reduction cooperation with suppliers and consumers for the industries of PPC & RCMCP, PSEP and SPFM are better than NMP and SPNM. And the SPFM gets the highest score.

It is shown by Model 3 that the interaction effect of REG and CDI on carbon reduction cooperation with suppliers and consumers is not significant. The environmental regulation does not have direct positive effect on promoting the carbon reduction cooperation with suppliers and consumer, and has no indirect effect on this kind of cooperation by influencing on other firms' carbon reduction practices as well.

(2) Determinants of carbon reduction cooperation with competitors or

surrogates

The BCM results for determinants of carbon reduction cooperation with competitors or surrogates are shown in Table 10. Both Logit model and Probit model were introduced in this study. The estimated results of the significance for each determinant are not significant different between the models. However, Hosmer-Lemeshow (H-L) statistic values show that the fitting degree of Probit model is better than Logit model. The VIF values of the independent variables in each model are all below 10, which show no multi-collinearity problem during the estimation. In order to avoid the heteroscedasticity during the regression, the estimation method of generalized linear model (GLM) was used by the application of EVIEWS 6.0. Firm size was considered as the only control variable in Model 4. Model 5 considered both firm size and industrial type as the control variables. Model 6 considered whether the interaction of REG and CDI had some effects on carbon reduction cooperation with competitors or surrogates. And LR statistic values of the three models are all high enough to reject the null hypotheses that the independent variables are not associated with the dependent variable.

Carbon reduction demand from the stakeholders in the supply chain is also the main driver for carbon reduction cooperation with competitors or surrogates. The carbon reduction pressures from suppliers and customers could promote the industrial firms to conduct carbon reduction practices (Zhang et al. 2012). Cooperation with competitors or surrogates is one of the options for carbon reduction. The defective infrastructure and mechanism is also the barrier that impedes carbon reduction cooperation with competitors or surrogates. The environmental regulation and imitating effect also play no significant role in this kind of cooperation.

Different with the cooperation with suppliers and customers, financial pressure has positive effect on carbon reduction cooperation with competitors or surrogates. Carbon reduction cost becomes an increasing expenditure for industrial firms since the climate change get more and more attention from the public in the recent years. In order to save the expenditure of carbon reduction, many industrial firms choose to cooperate with each other, for example, cooperation on carbon reduction R&D.

Firm size became the significant factor after industrial type was introduced in the model. It is indicated that the smaller firms are willing to cooperate with others on carbon reduction R&D for each industry. This might be attributed to the fact that smaller firms have more financial problems to conduct carbon reduction practices. The industry of PSEP gets the highest score on the performance of carbon reduction cooperation with competitors or surrogates.

From Model 6, we can see that the interaction effect of REG and CDI is also not significant on the implementation of carbon reduction cooperation with competitors or surrogates. There is also no indirect effect on this kind of cooperation from environmental regulation.

(3) Determinants of carbon reduction cooperation by industrial symbiosis

Table 11 shows the OCR results for the determinants of carbon reduction cooperation on the basis of industrial symbiosis. Both Logistic model and Normal model were introduced in this study according to the difference in pre-hypothesized probability distributions of F in formula (8). The estimated results of the significance for each determinant are not significant different between the models, which shows the robustness of the estimated results. The estimated threshold values c1-c4 are verified significantly (except c1 in Model 7), and increase hierarchically. This also indicates good estimations by OCR.

Table 10. BCM results for determinants of carbon reduction cooperation with competitors or surrogates

	Logit model			Probit model			Model 4 VIF	Model 5 VIF	Model 6 VIF
	Model 4-L	Model 5-L	Model 6-L	Model 4-P	Model 5-P	Model 6-P			
REG	-0.170 (-1.066)	-0.107 (-0.702)		-0.104 (-1.196)	-0.071 (-0.778)		1.192	1.063	
CDI	0.637*** (3.449)	0.687*** (3.376)	0.753*** (2.830)	0.393*** (3.584)	0.416*** (3.515)	0.463** (2.978)	1.025	1.058	1.058
IE	-0.179 (-1.066)	-0.204 (-1.075)	-0.203 (-1.069)	-0.103 (-1.005)	-0.129 (-1.153)	-0.128 (-1.150)	1.136	1.327	2.560
FP	0.285** (2.174)	0.308** (2.173)	0.309** (2.178)	0.168** (2.137)	0182** (2.173)	0.182** (2.177)	1.147	1.152	1.152
DIM	-0.201** (-2.127)	-0.226** (-2.195)	-0.226** (-2.200)	-0.125** (-2.148)	-0.138** (-2.262)	-0.138** (-2.265)	1.033	1.052	1.050
REG*CDI			-0.022 (-0.607)			-0.015 (-0.700)		2.495	2.495
Firm size	-0.111 (-1.125)	-0.193* (-1.745)	-0.193* (-1.745)	-0.066 (-1.091)	-0.112* (-1.707)	-0.113* (-1.711)	1.041	1.203	1.064
PPC& RCMCP		1.837*** (4.105)	1.839*** (4.111)		1.118*** (4.236)	1.119*** (4.241)		1.864	1.864
PSEP		3.523*** (4.643)	3.529*** (4.653)		2.067*** (5.108)	2.071*** (5.119)		1.358	1.358
NMP		1.216** (2.530)	1.215** (2.529)		0.758*** (2.618)	0.756*** (2.614)		1.663	1.662
SPFM		1.775*** (3.824)	1.779*** (3.832)		1.090*** (3.920)	1.092*** (3.930)		1.778	1.778
LR value	36.565	73.971	73.844	36.602	74.104	73.988			
McFadden R-squared	0.103	0.208	0.208	0.103	0.208	0.208			
H-L statistic	8.412	19.795	21.427	8.267	12.769	17.814			

Note:① *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$;② the data at the upside of the cell is the standard coefficient; the data at the bottom of cell is the t statistic value after robust standard error modifying.

There are not multi-collinearity problems during the estimation as well, since the VIF values of the independent variables in each model are all below 10. GLM estimation methods were used in this OCR model by the application of EVIEWS 6.0, where coefficient covariance matrix is estimated by quadratic hill climbing. Model 4 is the estimation only considered firm size as the control variable. Both firm size and industrial type are considered in Model 5 as the control variables. Model 6 considered whether the interaction of REG and CDI had some effects on carbon reduction cooperation by industrial symbiosis. And LR statistic values of the three models are all high enough to reject the null hypotheses that the independent variables are not associated with the dependent variable.

Table 11. OCR results for determinants of carbon reduction cooperation through industrial symbiosis

	Logistic model			Normal model			Model 7 VIF	Model 8 VIF	Model 9 VIF
	Model 7-L	Model 8-L	Model 9-L	Model 7-N	Model 8-N	Model 9-N			
REG	-0.090 (-0.694)	-0.049 (-0.372)		-0.022 (-0.295)	-0.003 (-0.039)		1.192	1.063	
CDI	0.871*** (5.320)	0.870*** (5.300)	0.913*** (4.149)	0.513*** (5.488)	0.513*** (5.453)	0.517*** (4.130)	1.025	1.058	1.058
IE	0.131 (0.925)	0.117 (0.814)	0.117 (0.813)	0.097 (1.139)	0.082 (0.939)	0.082 (0.939)	1.136	1.327	2.560
FP	0.064 (0.537)	0.047 (0.396)	0.048 (0.404)	0.033 (0.483)	0.028 (0.407)	0.029 (0.410)	1.147	1.152	1.152
DIM	-0.312*** (-3.772)	-0.315*** (-3.741)	-0.315*** (-3.743)	-0.199*** (-4.020)	-0.200*** (-3.979)	-0.199*** (-3.978)	1.033	1.052	1.050
REG*CDI			-0.013 (-0.411)			-0.001 (-0.065)		2.495	2.495
Firm size	-0.133 (-1.512)	-0.197** (-2.179)	-0.197** (-2.184)	-0.074 (-1.424)	-0.103* (-1.950)	-0.103* (-1.950)	1.041	1.203	1.064
PPC& RCMCP		1.255*** (3.555)	1.255*** (3.557)		0.726*** (3.489)	0.726*** (3.487)		1.864	1.864
PSEP		1.493*** (3.238)	1.492*** (3.235)		0.898*** (3.258)	0.898*** (3.257)		1.358	1.358
NMP		0.821** (2.126)	0.822** (2.129)		0.530** (0.293)	0.530** (2.293)		1.663	1.662
SPFM		1.011*** (2.730)	1.012*** (2.735)		0.588*** (2.664)	0.588*** (2.665)		1.778	1.778
c_1	1.268 (1.376)	1.903** (1.975)	2.068** (2.153)	0.888 (1.599)	1.279** (2.241)	1.291** (2.280)			
c_2	2.413*** (2.620)	3.119*** (3.222)	3.284*** (3.393)	1.571*** (2.835)	1.997*** (3.494)	2.009*** (3.534)			
c_3	2.940*** (3.179)	3.683*** (3.783)	3.848*** (3.948)	1.894*** (3.407)	2.340*** (4.075)	2.352*** (4.115)			
c_4	3.629*** (3.873)	4.404*** (4.460)	4.569*** (4.624)	2.311*** (4.108)	2.773*** (4.768)	2.786*** (4.814)			
LR statistic	66.087	82.531	82.562	68.362	84.201	84.204			
Pseudo R-squared	0.083	0.103	0.103	0.085	0.105	0.105			

Note:① *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$;② the data at the upside of the cell is the standard coefficient; the data at the bottom of cell is the Z statistic value after robust standard error modifying.

Carbon reduction demand from the stakeholders in the supply chain is also the main determinant that promotes carbon reduction cooperation by industrial symbiosis. And the main barrier that impedes this kind of carbon reduction cooperation is also attributed to the defective infrastructure and mechanism. However, different from the above two kinds of carbon reduction cooperation, financial pressure plays no significant role in carbon reduction cooperation by industrial symbiosis. Although there might be some transaction costs during the cooperation by industrial symbiosis, resource purchasing expenditure or waste emission cost would also decrease by the exchange of waste resources. The financial pressure from this kind of cooperation could be offset by these potential benefits.

From Model 9, there are also no significant effects on the implementation of carbon reduction cooperation by industrial symbiosis from interaction of REG and CDI. It is indicated that environmental regulations also attach no importance to carbon reduction cooperation by industrial symbiosis from both direct and indirect prospective.

Firm size also plays negative role in the implementation of carbon reduction cooperation by industrial symbiosis after industrial type was introduced in OCR. It is indicated that waste resources exchange for carbon reduction is easier to be implemented by the smaller firms.

4. Conclusion

To achieve sustainable development in response to the pressures from climate change, it is important for Chinese industrial companies to implement various kinds of CO_2 reduction practices. This study is designed to identify the determinants that drive or impede the CO_2 reduction practices implemented among industrial firms in China. And whether these CER practices have positive effects on the improvement of firms' performance is also assessed. Moreover, we specially focus on the practice of inter-firm collaboration on CER by industrial firms. The willingness and motivation for the industrial firms to cooperate with each other are explored in this study.

The results show that although some CO_2 reduction practices can bring significant environmental performance, few of them improve economic performance clearly. This indicates that environmental pressures are actually playing a larger role than economic ones. And the implementation of CO_2 reduction practices is still in an early stage for Chinese industrial companies. Economic benefits should be exploited to motivate industrial companies to conduct CO_2 reduction proactively and voluntarily.

The determinants of CER practices are various and a bit difference with our previous hypotheses. Firstly, regulatory factors have no significant effect on most practical CO_2 reduction activities, but can promote strategy-making for energy conservation and CO_2 reduction. Most regulations related to energy conservation or CO_2 reduction in China are generally flexible or voluntary so far (Zhu and Geng, 2013). Stricter regulations and higher enforcement level especially focused on industrial firms are needed to promote the CO_2 reduction practices. Secondly, *Pressures from supply chains* show positive influence on most CO_2 reduction practices, but play limited role in determining CO_2 reduction strategy. Chinese industrial companies have experienced market pressure from external relationships such as green purchasing and customer cooperation focusing on environmental concerns, and it is beneficial for them to implement pro-environmental practices in order to expand those markets. From this perspective, some governmental purchasing programs should also consider applying green procurement to promote IS companies' practices on energy conservation and CO_2 reduction. Moreover, *financial cost* is found to be an important factor which receives serious consideration in the implementation of most CO_2 reduction practices. Financial subsidies or tax breaks from the government, as a result, could be applied for promoting CO_2 reduction practices, especially at the initial stage of implementation. In addition, both *Imitating effect* and *Capacities* only play significant role in *Implementation of carbon crediting mechanism*. Although several companies have received large benefits from implementation of CDM, many companies still lag behind in carbon crediting due to the lack of capacities to obtain relevant information and knowledge. However, the practice of carbon crediting could be driven by the performance of the leaders on CDM projects. Government, therefore, can provide more platforms for the collection and distribution of the information related to carbon crediting, and strengthen the education system to train managers on the use of carbon crediting mechanisms.

Carbon reduction cooperation is an important option for Chinese industrial firms to implement CER practices. This paper characterized the carbon reduction cooperation through industrial chains into three types: carbon reduction cooperation with suppliers and consumers; carbon reduction cooperation with competitors or surrogates and cooperation through industrial symbiosis. The willingness to participate in the above CER cooperation practices is explored in this study.

The results show that carbon reduction cooperation through industrial chain is totally at an elementary stage. Many industrial firms have just realized the effectiveness to reduce the carbon emission through this kind of cooperation. Carbon reduction demand from other stakeholders in the industrial chain is the main driver for the carbon reduction cooperation. And defective infrastructure and mechanism are the main barrier that impedes the inter-firm cooperation on carbon emission reduction. Financial pressure plays a negative role in carbon reduction cooperation with suppliers and customers, but has a positive effect on R&D of carbon reduction cooperation with competitors or surrogates. However, its effects on carbon reduction cooperation through industrial symbiosis are not significant. Hypothesis 4 is partially verified.

Environmental regulation has no direct effects on carbon reduction cooperation, and also does not have any indirect effects by influencing other stakeholders' carbon reduction awareness on the industrial chain. This somewhat reflects current environmental regulation system in China has not effectively put enough pressures on industrial firms' carbon reduction practices. There are few strict regulations and higher enforcement level for industrial firms to care about their carbon emission problems.

Imitating and demonstrating effects on carbon emission reduction have not come into work at present in China. Hypothesis 3 is not verified as well. This might be largely due to the starting step for carbon reduction cooperation for Chinese industrial firms as a whole. There are not many successful cases of carbon reduction cooperation at present.

Carbon reduction cooperation through industrial symbiosis attaches significant importance to the environmental performance of industrial firms. However, carbon reduction cooperation with suppliers, customers and R&D cooperation with competitors play limited role in the improvement of environmental performance.

The improvement of environmental performance could promote the industrial firms' economic performance. Carbon reduction cooperation through industrial symbiosis also has positive effects on economic performance of industrial firms, but the effects are mostly independent on its effects on the improvement of environmental performance. Carbon reduction cooperation with suppliers and customers could also improve the economic performance of industrial firms, but the effects are smaller than cooperation through industrial symbiosis. The positive effects by cooperation with competitors or surrogates have not come out yet.

There is still a great potential to enrich this study although some valuable findings have been gained. We only gave a general framework of CER practices and inter-firm cooperation on carbon emission reduction in this paper. More detailed performance of carbon reduction cooperation needs to be focusing on in the future research. In addition, questions about how to conquer the barriers of CO_2 reduction practices to improve both environmental and economic performance require further research.

Appendix A. Descriptive statistics of each item

	Items	No.	Mean	Std. dev.	Rotated Component Matrix				
					1	2	3	4	5
CO_2 abatement practices									
Innovation (Cronbach's Alpha= .898)	R&D investment on energy saving or carbon abatement technology	85	3.341	1.427	.323	.857	.038	.032	
	Retrofit the production process for energy saving and carbon abatement	85	3.259	1.457	.278	.886	.172	.087	
	Replacing equipments with energy efficient ones	85	3.400	1.390	.167	.823	.175	.238	
Residue recycling (Cronbach's Alpha= .907)	Recycling residual energy (e.g. residual heat)	85	2.541	1.444	.046	.190	-.018	.883	
	Recycling scrap materials (e.g. blast furnace slag)	85	2.506	1.436	.151	.200	-.017	.880	
	Recycling by-product (e.g. coke oven gas, furnace gas)	85	2.941	1.456	.120	-.070	.210	.825	
Implementation of carbon crediting mechanism (Cronbach's Alpha= .875)	Application of CDM projects	85	2.177	1.093	.849	.299	.178	.107	
	Sell the credits of reduced carbon from CDM	85	1.753	0.8438	.815	.196	.293	.182	
	Construction of carbon reduction accounting system	85	1.600	0.7270	.880	.296	.115	.095	
CO_2 abatement strategy (Cronbach's Alpha= .875)	Short-term objective for energy saving or carbon abatement	85	3.523	1.140	.263	.169	.847	-.028	
	Long-term vision for energy saving or carbon abatement	85	3.318	1.217	.016	.077	.884	.227	
	Clear plan for energy saving or carbon abatement	85	3.200	1.233	.252	.112	.863	-.023	
Determinants									
Regulatory policies (Cronbach's Alpha= .907)	Central governmental regulations on energy conservation and CO_2 reduction	85	3.506	1.278	.875	.237	-.031	-.095	-.145
	Regional governmental regulations on energy conservation and CO_2 reduction	85	3.118	1.219	.899	.044	.170	-.073	.135
	Export countries' regulations on energy conservation and CO_2 reduction	85	3.271	1.357	.926	-.002	.165	-.066	.080
Pressures from supply chains (Cronbach's Alpha= .828)	Requirements from customers on energy-saving and CO_2 abatement	85	3.141	1.187	.107	-.066	.020	.869	.069
	Requirements from suppliers on energy-saving and CO_2 abatement	85	3.200	1.213	-.122	.129	-.199	.843	.118
	Requirements from material recyclers on energy-saving and CO_2 abatement	85	3.435	1.210	-.291	.176	-.008	.831	-.120
Imitating effect (Cronbach's Alpha= .874)	Competitors have taken some practices on energy-saving and CO_2 abatement	85	3.765	1.278	.002	.149	.914	.043	.150
	Substitution producers have taken some practices on energy-saving and CO_2 abatement	85	3.977	1.112	.083	.189	.872	-.118	.179
	Industrial leaders have taken some practices on energy-saving and CO_2 abatement	85	3.659	1.129	.310	.139	.749	-.131	.209
Financial cost (Cronbach's Alpha= .772)	High investment of R&D on energy-saving and CO_2 abatement	85	3.235	1.306	-.012	.147	.055	.190	.796
	High cost for equipment replacement and process retrofit	85	3.600	1.146	-.120	.201	.238	-.131	.804
	Insignificant benefits from energy-saving and CO_2 abatement in short-term	85	3.224	1.169	.236	-.038	.240	.008	.803
Capacities	Lack of advanced technology on energy-saving and CO_2 abatement	85	3.977	0.859	.106	.899	.114	.082	.110

(Cronbach's Alpha= .892)	Lack of qualified people to solve energy-saving and CO_2 abatement issues	85	3.882	0.851	.040	.890	.109	.125	.162
	Lack of information channels on energy-saving and CO_2 abatement	85	3.965	0.837	.099	.851	.217	-.001	.031
Performance									
Environmental performance	Reduction of green house gas emission	85	3.2588	1.02531	.826	.266			
(Cronbach's Alpha= .894)	Reduction of waste discharge	85	3.3882	1.07009	.842	.264			
	Decrease of frequency for environmental accidents	85	3.2941	1.04453	.869	.044			
	Improve company's social image	85	3.4235	1.00447	.848	.285			
Economic performance	Decrease cost for energy consumption	85	3.1765	1.05983	.191	.825			
(Cronbach's Alpha= .841)	Decrease the fee for waste treatment	85	3.2824	1.04211	.152	.882			
	Improvement on reducing the investment	85	3.1059	1.12359	.231	.820			
	Improvement on reducing the operation cost	85	2.9765	1.10169	.208	.777			

Reference

Barker, T.J., Zabinsky,Z.B., 2008. Reverse logistics network design: a conceptual framework for decision making. International Journal of Sustainable Engineering 1(4): 250–260.

Bonte W., 2008. Inter-firm trust in buyer–supplier relations: Are knowledge spillovers and geographical proximity relevant? Journal of Economic Behavior & Organization 67: 855–870.

Carter RC, Carter JR.,1998. Interorganizational determinants of environmental purchasing: initial evidence from the consumer products industry. Decision Sciences 29(3): 28-38.

Carter, C.R., Ellram, L.M., Ready, J., 1998. Environmental purchasing: benchmarking our German counterparts. International Journal of Purchasing and Materials Management 34 (4), 28–38.

Chaabane, A., A. Ramudhin, et al., 2012. Design of sustainable supply chains under the emission trading scheme. International Journal of Production Economics 135(1): 37-49.

Chan RYK, Lau LBY., 2001. Explaining green purchasing behavior: a cross-cultural study on American and Chinese consumers. Journal of International Consumer Marketing 14(2/3): 9-41.

Darnall, N., Jolley, G.J., Handfield, R., 2008. Environmental management systems and green supply chain management: complements for sustainability? Business Strategy and the Environment 17 (1): 30-45.

Dean, J.W., Snell, S.A., 1991. Integrated manufacturing and job design: moderating effects of organizational inertia. Academy of Management Journal 34 (4): 776–804.

del Brio, J.A., Junquera, B., Ordiz, M., (2008). Human resources in advanced environmental approaches: a case analysis. International Journal of Production Research 46 (21), 6029-6053.

DiMaggio, P.J., Powell, W.W., 1983. The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. American Sociological Review 48: 147-160.

Ebinger, F., Goldbach, M., Schneidewind, U., 2006. Green supply chains: a competence-based perspective. In: Sarkis, J. (Ed.), Greening the Supply Chain. Springer, pp. 251-270.

Frota Neto, J. Q., Bloemhof-Ruwaard, J.M., et al., 2008. Designing and evaluating sustainable logistics networks. International Journal of Production Economics 111 (2): 195–208.

Gielen, D.J., (1997). Technology characterization for ceramic and inorganic materials. Input data for Western European MARKAL, ECN-C-97-064, Energy Research Centre of The Netherlands, Petten.

Gielen, D. and Y. Moriguchi (2002). CO_2 in the iron and steel industry: an analysis of Japanese emission reduction potentials. Energy Policy 30(10): 849-863.

Gil, A.M.J., Jimenez, J.B., Lorente, J.C., 2001. An analysis of environmental management, organizational context and performance of Spanish hotels. Omega 29 (6): 457-471.

Guo, H., Yin, Z., (2007). Range of recovery of exhaust heat in metallurgical enterprises. Iron & Steel 2, 77–81 (in Chinese).

Guo, Z. and Fu, Z. (2010). Current situation of energy consumption and measures taken for energy saving in the iron and steel industry in China. Energy 35 (11): 4356–4360

Hashimoto, S., T. Fujita, et al., 2010. Realizing CO_2 emission reduction through industrial symbiosis: A cement production case study for Kawasaki. Resources, Conservation and

Recycling 54(10): 704-710.
Henri, J. F. and M. Journeault, 2010. Eco-control: The influence of management control systems on environmental and economic performance. Accounting, Organizations and Society 35(1): 63-80.
Hou, J.T., Wen, Z.L., Cheng, Z.J., 2004. Structural equation model and its application. Science and Education Press, ISBN: 978-7-50412-816-4. (In Chinese)
Huang, F.M., 2005. Structural equation model: theory and application. China's Tax Press, ISBN: 978-7-80117-733-9. (In Chinese)
Huang, D., (2010). Energy efficiency in China iron and steel industry. Available at: http://220.156.189.23/seminars/document/2010/Energy Efficiency in CHN Steel Huang Dao.pdf
Hugo, A., Pistikopoulos, E.N., 2005. Environmentally conscious long-range planning and design of supply chain networks. Journal of Cleaner Production: Recent advances in Industrial Process Optimization 13 (15): 1471–1491.
IEA. CO_2 EMISSIONS FROM FUEL COMBUSTION, (2011). Available at http://www.iea.org/co2highlights/CO_2highlights.pdf.
International Iron and Steel Institute (IISI), 2005. Steel Statistical Year Book 2005.
IPCC, (2006). IPCC guidelines for national greenhouse gas inventories. Available at: http://www.ipcc.ch/ipccreports/methodology-reports.htm
Jayaraman, V., 2006. Production planning for closed-loop supply chains with product recovery and reuse: an analytical approach. International Journal of Production Research 44(5): 981–998.
J.A. Poyago-Theotoky., 2007. The organization of R&D and environmental policy. Journal of Economic Behavior & Organization 62: 63–75.
Jones, C., 2010. Exploring new ways of assessing the effect of regulation on environmental management. Journal of Cleaner Production 18: 1229-1250.
Jørgensen, M.S., Jørgensen, U., Hendriksen, K., Hirsbak, S., Thomsen, H.H., Thorsen, N., 2010. Environmental management in Danish transnational textile product chains. Management Research Review 33 (4): 357-379.
Korhonen, J. and J. P. Snäkin, 2005. Analyzing the evolution of industrial ecosystems: concepts and application. Ecological Economics 52(2): 169-186.
Li, H., L. Wang, et al., 2012. Study of the potential of low carbon energy development and its contribution to realize the reduction target of carbon intensity in China. Energy Policy 41: 393-401.
Li, J., Fan, W., Guo, J., (2010). Analysis of Producer Gas Desulphurization for Metallurgical Lime Kiln. Fire-resistant and Lime 35 (1): 15-18. (In Chinese)
Liao, (2011). Accelerating the diversification of China's iron ore imports. Shanghai Securities News, Available at: http://news.xinhuanet.com/fortune/2011-08/24/c_121902221.htm (In Chinese)
Lieckens, K., Vandaele, N., 2007. Reverse logistics network design with stochastic lead times. Computers and Operations Research 34 (2): 395–416.
Liu, Y., et al., (2008). Countermeasures against international pressure of reducing CO_2 emissions and analysis on China's potential of CO_2 emission reduction. Acta Geographica Sinica 63, 676–677 (in Chinese).

Liu W et al., 2010. Development framework and scientific foundation for low-carbon economy in China. Commercial Press, ISBN 978-7-100-07143-7. (In Chinese)

Lopéz A., 2008. Determinants of R&D cooperation: Evidence from Spanish manufacturing firms. International Journal of Industrial Organization, 26: 113-136.

López-Gamero, M. D., J. F. Molina-Azorín, et al., 2010. The potential of environmental regulation to change managerial perception, environmental management, competitiveness and financial performance. Journal of Cleaner Production 18(10-11): 963-974.

Lu, L.Y.Y., Wu, C.H.,et al., 2007. Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis. Sustainable Design and Manufacture, International Journal of Production Research 45 (18-19): 4317–4331.

Luo, Y., Zhou, M., et al., 2001. An integrated E-supply chain model for agile and environmentally conscious manufacturing. IEEE/ASME Transactions on Mechatronics 6(4): 377–386.

Mason C, Perreault WD. Collinearity, power, and interpretation of multiple regression analysis. Journal of Marketing Research 1991; 28(3):268-80.

MIIT, 2011. Issued notice about the elimination of backward production capacity of industrial objectives and tasks in 2011. Available at: http://finance.sina.com.cn/china/bwdt/20110711/104810125706.shtml (In Chinese)

NBS, 2009. National Statistical Yearbook on industry and energy. Available at http:// tongji.cnki.net/ kns55/navi/HomePage.aspx?id=N2009060138&name=YCXME&floor=1

Nishitani, K., S. Kaneko, et al., 2012. Are firms' voluntary environmental management activities beneficial for the environment and business? An empirical study focusing on Japanese manufacturing firms. Journal of environmental management 105: 121-130.

Nunnally JC, Bernstein IH. Psycometric theory. 3rd ed. New York: McGraw-Hill; 1994.

Okamuro H., 2007. Determinants of successful R&D cooperation in Japanese small businesses: The impact of organizational and contractual characteristics. Research Policy 36: 1529–1544.

Pochampally, K. K., Nukala, S., et al., 2009. Strategic planning models for reverse and closed-loop supply chains, vol. xvii. CRC Press, Boca Raton 273p.

Prajogo, D., A. K. Y. Tang, et al., 2012. Do firms get what they want from ISO 14001 adoption?-An Australian perspective. Journal of Cleaner Production 33: 117-126.

Presley, A., Meade, L., Sarkis, J., (2007). A strategic sustainability justification methodology for organizational decisions: a reverse logistics illustration. International Journal of Production Research 45 (18-19), 4595-4620

Puran Mongia, Katja Schumacher, Jayant Sathaye, 2001. Policy reforms and productivity growth in India's energy intensive industries. Energy Policy 29: 715-724.

Ren, L. and W. Wang (2011). Analysis of Existing Problems and Carbon Emission Reduction in Shandong's Iron and Steel Industry. Energy Procedia 5: 1636-1641.

Rivera, J., 2004. Institutional pressures and voluntary environmental behavior in developing countries: evidence from the Costa Rican hotel industry. Society & Natural Resources 17 (9): 779-797.

Rynikiewicz, C. (2008). The climate change challenge and transitions for radical changes in the European steel industry. Journal of Cleaner Production 16(7): 781-789.

Sarkis, J., Presley, A., Liles, D., 1997. The strategic evaluation of candidate business process reengineering projects. International Journal of Production Economics 50 (2-3): 261-274.

Sheu, J.-B., 2008. Green supply chain management, reverse logistics and nuclear power generation. Transportation Research Part E: Logistics and Transportation Review 44(1): 19–46.

Sheu, J.-B.,Chou,Y.-H.,et al., 2005. An integrated logistics operational model for green-supply chain management. Transportation Research Part E: Logistics and Transportation Review 41 (4): 287–313.

Simonsson, A., 2002. Application of sustainable product development and designed pilot study of the state of the art, barriers and enablers. Master's thesis, LiTH-IFM-Ex-1072. Department of Physics and Measurement Technology, Linköping University, Sweden; 2002.

Steiger J H., 1990 Structural model evaluation and modification: An interval estimation approach [J]. Multivariate Behavioral Research, 25:173–180.

Testa, F., Iraldo, F., (2010). Shadows and lights of green supply chain management: determinants and effects of these practices based on a multi-national study. Journal of Cleaner Production 18, 953-962.

van Hemel, C., Cramer, J., 2002. Barriers and stimuli for eco-design in SMEs. Journal of Cleaner Production 10: 439-53.

Wang, K., C. Wang, et al., (2007). Scenario analysis on CO_2 emissions reduction potential in China's iron and steel industry. Energy Policy 35(4): 2320-2335.

Worldsteel, (2010). Steel Statistical Yearbook 2010. Available at :http://www.worldsteel.org/statistics/statistics-archive.html.

Yin, H., Ma, C., 2009. International integration: a hope for a greener China? International Marketing Review 26 (3): 348-367.

Zeng, S., Y. Lan, et al., (2009). Mitigation paths for Chinese iron and steel industry to tackle global climate change. International Journal of Greenhouse Gas Control 3(6): 675-682.

Zhang, B., Bi, J., Yuan, Z., Ge, J., Liu, B., Bu, M., 2008. Why do firms engage in environmental management? An empirical study in China. Journal of Cleaner Production 16: 1036-1045.

Zhang B., Zhaohua Wang, Jianhua Yin, Lixia Su. CO_2 emission reduction within Chinese iron & steel industry: practices, determinants and performance. Journal of Cleaner Production, 2012, 33: 167-178.

Zhang, X. P. and X. M. Cheng, 2009. Energy consumption, carbon emissions, and economic growth in China. Ecological Economics 68(10): 2706-2712.

Zhao M., Zhang W., Yu L., (2009). Carbon Emission from Energy Consumption in Shanghai. Research of Environmental Sciences 22 (8):984-989.

Zhu, Q., J. Cordeiro, et al. 2012. International and domestic pressures and responses of Chinese firms to greening. Ecological Economics 83:144-153.

Zhu, Q., Sarkis, J., Geng, Y., 2005. Green supply chain management in China: pressures, practices and performance. International Journal of Operations and Production Management 25 (5): 449-468.

Zhu, Q., Sarkis, J., Lai, K., 2007. Green supply chain management: pressures, practices and performance within the Chinese automobile industry. Journal of Cleaner Production 15: 1041-1052.

Zhu, Q. and Y. Geng, 2013. Drivers and barriers of extended supply chain practices for energy saving and emission reduction among Chinese manufacturers. Journal of Cleaner

Production 40(0): 6-12.
Zhu Q., Yong Geng, Kee-hung Lai., 2010 Circular economy practices among Chinese manufacturers varying in environmental-oriented supply chain cooperation and the performance implications. Journal of Environmental Management, 91 (6): 1324-1331.
Zou, K., (2008). Baosteel Energy-saving & Emission-reducing Practice. Available at: http://www.asiapacificpartnership.org/pdf/Steel/5th_meeting/4-3%28Baosteel%29.pdf (In Chinese)
Zsidisin, G.A., Hendrick, T.E.,(1998). Purchasing's involvement in environmental issues: a multi-country perspective. Industrial Management & Data Systems 7, 313-320.

About the Author

Dr. Zhaohua WANG current is serving as a professor of the School of Management and Economics, Beijing Institute of Technology, China. He was a research fellow at the Institute of Developing Economies (IDE-JETRO), Chiba, Japan, from July 2013 to September 2013, where he conducted his research project. Currently his research interest lies in the firms' energy consumption behavior, energy and environmental policy and green supply chain management. He has published 3 monographs and more than 90 articles in reputed journals. As a chief Principal, Prof. Wang conducts more than 20 research projects, including National Natural Science Fund of China, National Social Science Fund of China, the National Basic Research Program of China (973 Program), and so on. He can be reached via wangzh@hotmail.com.