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The growth of carbon markets in Asia: The potential challenges for future development

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ADB Working Paper Series

**THE GROWTH OF CARBON MARKETS
IN ASIA: THE POTENTIAL CHALLENGES
FOR FUTURE DEVELOPMENT**

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and Xiaohang Ren

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Abstract

This paper is designed to provide comprehensive details on the carbon markets across the major Asian economies and with specific attention to the Chinese carbon market. We particularly discuss the carbon markets across the major northeast (the People's Republic of China [PRC], Japan, and the Republic of Korea) Asian economies. Further, we empirically explore the interrelationship between the Shanghai and Shenzhen carbon emission markets, using an autoregressive distributed lag (ARDL) model with daily high-frequency data from 3 January 2017 to 9 October 2018. The evidence from the analysis confirms unidirectional influence from the Shanghai carbon emission market on the Shenzhen carbon emission market. Our findings shed light on the carbon emission markets' policy formulation for the Chinese government to achieve sustainable economic growth and meet carbon reduction targets in the PRC. Finally, we provide numerous policy and practical implications for the Asian economies with respect to the issues of climate change policies.

Keywords: carbon emission markets, ARDL model, interrelationship, People's Republic of China

JEL Classification: D53, O21, Q38, Q51, Q56, R11

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1. INTRODUCTION

Over the past 20 years, academia and industry practitioners have persistently paid a lot of attention to studying how to efficiently address global climate change and decrease carbon emissions. Historically, it is widely believed that emission trading programs have played a prominent role in environmental policy, especially for the purpose of reducing carbon emissions. As a result, a multiplicity of regional and national carbon trading markets emerged, including the Regional Emissions Trading Scheme in Australia, the PRC, New Zealand, the Republic of Korea, and the United States, and most notably the Emissions Trading System set up by the European Union (EU). As far as we are concerned, to date the European Union Emissions Trading System (EU ETS) is the major emission cap-and-trade trading program across the world, accounting for about \$175 billion a year. The history of the EU ETS can be traced back to 2005, and today it allocates tradable emissions permits to more than 12 large power stations and industrial plants in more than 20 countries, accounting for about half of the EU's total greenhouse gas emissions in aggregate.

Previous research has focused on the impacts of energy, financial markets, and macroeconomic factors on the EU carbon emission market (see, for instance, Alberola, Chevallier, and Cheze 2008; Chevallier 2009; Koch 2014). However, to the best of our knowledge, fewer studies have focused on the relationship between the PRC's carbon emission markets and the EU carbon emission market. As the largest greenhouse gas emitter, the Chinese government has given a lot of attention to setting up carbon trading markets, such as the Shanghai carbon emission market and the Shenzhen carbon emission market. Therefore, the growth of carbon emission markets in the PRC has raised the question: What is the relationship between regional carbon emission markets? Moreover, the lessons from the linkages between regional carbon emission markets could help to enhance the carbon emission market cooperation both in the PRC and around the world, and provide additional insight for other developing countries into the domestic emissions trading system. Our main empirical findings suggested the existence of cointegration between the futures prices in the PRC's carbon emission markets. In particular, the Shanghai carbon emission market positively affects the Shenzhen carbon emission market, but a similar vice versa relationship could not be found. Our findings shed light on the carbon emission markets' policy formulation for the Chinese government to achieve sustainable economic growth and meet carbon reduction targets in the PRC.

Since the well-known economic revolution that started in the late 1970s, the economy of the PRC has undergone decades of significant developments and became the second largest economy in the world in 2016, according to the World Bank's GDP data at the end of 2017. Despite its undebatable economic success, a side effect of the PRC's economic progress is the unprecedented large volume of carbon emissions. As a result, the National Development and Reform Commission of the People's Republic of China issued "interim measures for voluntary greenhouse gas emissions trading management" in June 2012, to explore the possibility of a voluntary emissions trading program in the PRC. This is the PRC's initial attempt to reduce carbon emissions and has been generally regarded as a signal to the public. It lays out the theoretical foundation for further practical implementation of mandatory carbon trading mechanisms as well as the establishment of carbon emission rights exchanges in Shanghai, Shenzhen, and other places in the PRC. As a matter of fact, the first carbon emission exchange in the PRC was set up in Shenzhen in June 2013, and Shanghai and other places had followed suit by the end of November 2013. These have since become the two most important carbon emission exchanges in the PRC, parallel to the two most important stock exchanges in

the country in Shanghai and Shenzhen. Given the current prominent status of the PRC's economy, a significant reduction in the level of carbon emissions of the Chinese stock market will be expected from these programs.

In theory, the establishment of carbon emission markets will significantly decrease the level of the PRC's carbon emissions, which has milestone implications for the PRC's carbon emission reductions. In practice, however, there was only a trivial volume prior to 2007, and to date, to the best of our knowledge, no paper has discussed the interrelationship among the futures prices in multiple carbon emission exchanges in the PRC while a large strand of literature has already discussed the interrelationship between the stock prices in the Shanghai and Shenzhen stock exchange. This paper aims to focus on the two most important carbon emission exchanges in the PRC (i.e., the Shanghai and Shenzhen carbon emission exchanges). To be specific, it will examine whether the futures price in the Shanghai carbon emission exchange affects the futures price in the Shenzhen carbon emission exchange, and whether the futures price in the Shenzhen carbon emission exchange affects the futures price in the Shanghai carbon emission exchange, taking into account the exogenous shock mainly from the EU ETS. This paper will contribute to the existing literature in the following three ways: First, this paper is the first to investigate the dynamic linkage of the futures prices between these two markets. The study results will shed light on the interrelationship of the futures prices in these two markets and provide risk management guidelines for the two markets' investors. Second, this study applies daily high-frequency data from 3 January 2017 to 9 October 2018. An investigation into the futures price on a lower-frequency level will not be able to capture the dynamic influence, while intraday high-frequency data will suffer from much misconstruction noise in this study. Third, we introduce the autoregressive distributed lag model to this topic, which integrates short-run adjustment effects with long-run equilibrium without losing information (see Jalil and Feridun 2011).

2. BACKGROUND

In the last few years, the carbon emission market has emerged to become a prominent system for mitigating climate change across the globe. This recent trend has focused the attention of Association of Southeast Asian Nations (ASEAN) countries on this modern and global idea of mitigating climate change, having noted the rate at which emissions continue to increase in the region. Northeast Asian countries such as the PRC, Japan, and the Republic of Korea contribute more than one-fifth of the world's GDP and more than a quarter of global emissions (Ewing 2016a). Equally, the increase in emissions in Southeast Asia is almost sprinting forward at the same rate as the economic growth, with nearly a 5% annual increase from 1990 to 2010 (Raitzer et al. 2015). This surge has been traced to the relative escalation of emissions in sectors such as manufacturing and transportation. These two sectors are associated with the region's structural change rather than rural or agrarian areas.

There is, therefore, an urgent need to curtail the increase in emissions, owing to the fact that emissions cause much harm to humanity and the economy as a whole. Given that, the global carbon finance needs to be upheld by an order of "weight-carrying" in the second commitment period of the Kyoto Protocol. To enable the stakeholders in the carbon market to see the opportunities far away, outside the project-based Clean Development Mechanism (CDM), alternative schemes such as allowance-based market mechanisms may be considered in the emerging economies in a similar manner to the one that functions in Europe, i.e., the European Union Emissions Trading Scheme (EU ETS) (Grubb 2012; Perdan and Azapagic 2011). Evidently, there has been

significant progress in this market as the trend has gained popularity among the major Asian economies, including the PRC, India, Japan, Kazakhstan, and the Republic of Korea. In the case of the PRC, which is the world's major growing market, it is expected that it has a greater potential for the scale of carbon trading (Jotzo, De Boer, and Kater 2013; Wang 2013; Fankhauser 2011; Guan and Hubacek 2010).

Based on the above, we see clearly the significance of carbon emission mechanisms and they are considered popular instruments in the domestic and international circuit for enhancing efforts toward mitigating climate change. These instruments often put a price tag on emissions that lead to climate-damaging greenhouse gases, which eventually leads to the promotion of climate change mitigation efforts. More specifically, there are two approaches that led to the creation of carbon markets, i.e., the cap-and-trade mechanism and the carbon tax mechanism (Hartmann 2017).

Cap-and-trade mechanism: The cap-and-trade mechanism is used by governments or intergovernmental bodies to peg a limit to greenhouse gas emissions in a given period of time. This mechanism is designed to offer licenses to both companies and industries with a view to minimizing the growth of pollution (Stavins 2008). The scheme is designed in such a way that if companies that do not meet their cap buy licenses from others, they will have a surplus. The technicality here is that it provides an opportunity to reduce greenhouse gases with a cost-effective platform. However, it is also widely criticized, because it rewards most polluters with windfall profits, whilst undermining the efforts to reduce pollution and achieve a more sustainable economy.

Despite this criticism, its popularity remains high, going by the wide range of potentials, which can engender considerable revenues. These collected revenues have significant implications for distribution in the spirit of fairness and economic growth. The possible uses of carbon revenues could include: i) counterbalancing the unequal effects of high energy prices on low-income households in the form of discounts on electricity bills; ii) providing transitional assistance (e.g., arranging or providing financial support for job training) for communities and individuals whose livelihood depends on fossil fuels; iii) providing financial support for communities that face an unequal burden from carbon emissions from fossil fuels; and iv) investing in clean/renewable energies, energy-efficient technologies, and clean vehicles, which all play an important role in moving the economy from a carbon-intensive to a clean-energy economy.

In addition, cap and trade in the form of emissions trading schemes (ETS) has progressed faster and attracted the attention of policy makers and practitioners in the last few years. For instance, in 2014, 18 ETS programs were initiated across 18 national and subnational jurisdictions. This initiation was planned for one more country and was also under consideration for implementing in 11 more national and subnational jurisdictions (World Bank 2014). Subsequently, the implementation and planning of emissions trading schemes spread across all regions except for Africa. Furthermore, the emissions trading schemes covered nearly 9% of global greenhouse gas emissions by 2015. Prior to 2015, the World Bank (2014) documented that the majority of implemented ETS programs have made landslide achievements in recent years in terms of scope, linkages, and development of approaches. To this end, it could be said that the cap-and-trade mechanism is gaining ground among European, Asian, and North American countries. Hopefully, this may also potentially spread to other regions such as sub-Saharan Africa and Africa.

Carbon tax mechanism: Carbon tax is another mechanism used to curtail excessive emissions around the world. In particular, carbon tax is a form of tax whereby each unit of greenhouse gas emissions gives participating firms (and households, depending on the scope) an incentive to reduce pollution (Taschini, Dietz, and Hicks 2013). Hence, the rate of pollution is reduced, depending on the chosen level of tax. For these reasons, carbon tax could be assessed by taking into account the cost or damage associated with each unit of pollution and the cost associated with controlling that pollution. Therefore, getting the tax level correct is the key, even though some firms and households will most likely opt for paying the taxes while continuing to pollute the environment, beyond and above what is optimal for society. If there is a high level of pollution then the cost will rise higher than necessary to reduce emissions, and it will have a considerable impact on profits, jobs, and end use consumers.

It is also important to highlight here that carbon tax can cause an increase in business overheads; in this case, companies will be pushed to find efficient ways to manufacture their products and/or deliver their services, as this would be beneficial to their bottom-line users. This idea supports more environment-friendly and creative ideas among industries. Furthermore, carbon emissions have also been linked to worsening public health as they have a major impact on the quality of the air we breathe. However, implementing a carbon tax could improve air quality by reducing carbon emissions, thereby decreasing the rate of respiratory issues and the number of asthma attacks (Kramer and Fraser-Hidalgo 2018).

Based on the above, many countries have demonstrated knowledge of carbon trading via various approaches hinged on the flexibility of carbon taxes to fit into national circumstances. For instance, in 2014, over 14 countries implemented carbon tax approaches to fight or reduce the level of emissions in their countries. These countries are particular in nature as some took various approaches in the light of national circumstances (to enable the use of carbon taxes together with other carbon pricing appliances), while others turned towards approaches that considered industry competitiveness (World Bank 2014).

On the other hand, politicians around the world favored the use of the carbon trading option over the second option—carbon tax. This is because in the carbon trading scheme, each participant firm is given a certain emission allowance quota in the primary ETS market, and then trades with other members in the secondary ETS market for extra allowance to support its ongoing production or for benefits if the permitted quote is not utilized (Tang, Shi, and Bao 2016; Zhang, Wang, and Tan 2015). Usually in the initial stages of trading, the emission allowance quota is either given to businesses for free or has to be purchased at auction. Therefore, over time the number of existing permits reduces, putting more pressure on participating firms to invest more money in production technologies to reduce the growth of carbon emissions. Hence, this approach will help firms to come up with more innovations, which will significantly assist them in reducing the price of new technologies.

3. THE GROWTH OF CARBON MARKETS IN THE ASIA REGION

In recent times, the issue of climate change has become a global agenda as many efforts have been made to meet the Paris Agreement (PA). Specifically, the participating countries are dedicated and prepared to address the climate change issue through various means. To date, 175 countries around the world have ratified the Agreement, including, among other Asian countries, countries in Northeast and

Southeast Asia (Ewing 2016a). This section seeks to explore the current status in the Asia region, particularly in the major economies of Northeast Asia. To address the increasing concerns around the issue of climate change, the major economies in the Northeast Asia region have developed carbon markets. The growth of carbon markets has been very impressive in the last few years. More specifically, the number of carbon markets has doubled since 2012 and the general interest in carbon trading is also on an upswing. Further, it is noted that emission pricing is worth \$50 billion (Ewing 2016b). In the following, we discuss three major Northeast Asian economies, namely the PRC, Japan, and the Republic of Korea.

PRC: The main objective of the Kyoto Protocol is to address the issue of climate change by introducing a proper market mechanism. It has been noted in the recent past that the international carbon market is growing rapidly and is well diversified across various forms of markets, such as the Clean Development Mechanism (CDM), voluntary emission reduction (VER), and emission allowance trading. The PRC is not an exception, as it has challenged itself to build a more formidable carbon market, having realized the volatile nature of an economy in which carbon emissions are at an extreme level due to industrialization. As a result, in 2011 the PRC pledged its support towards promoting low carbon emission development through carbon trading where the set target of energy consumption per unit of GDP would drop by 3.4% in 2014 and 2.32% in 2015 (the Economist 2015). By the end of September 2017, the market had covered 3,000 entities from more than 20 industry sectors, with the total trading volume reaching 200 million tCO₂e while the total trading value was about 45.1 billion yuan and the price ranged from 1 to 123 yuan/tCO₂e (EDF 2017). This is therefore an indication that the carbon markets in the PRC are gaining momentum, and moving towards achieving a low-emission economy.

As an addendum to the above, huge successes have been recorded in the reduction of carbon emissions (mainly in the power sector) with an estimated 0.09 billion tCO₂e difference when compared to the level of 2016. As for fossil fuel power generation, it will reach 4.88 Kwh and an average efficiency of 305 gce/Kwh by 2020. By contrast, there was a 0.06 trillion kWh increase in nonfossil fuel power generation in 2016, and this is expected to reduce to 0.51 trillion tCO₂e by 2020 (EDF 2017). This therefore implies that the PRC adopted all carbon mechanisms to achieve its slated plan.

In the ongoing effort to achieve a stronger carbon market, the PRC is establishing strong cooperation with other international counterparts with respect to carbon pricing. For instance, in October 2017, both the PRC and the EU declared that there would be continued collaboration on emissions trading. On this platform, it is agreed that the EU will continue to provide support to help the PRC develop its national ETS for a period of three years (EU 2017). In addition, on 4 December 2017, the Chinese and Canadian governments released a joint declaration on climate change, which basically explains their commitment to strengthening their collaboration, particularly in regard to clean energy and carbon markets (Government of the PRC 2017).

A number of researchers have also considered the price dynamics of CO₂ allowances in order to explain the position of emissions. Some authors argue that the PRC's carbon market is competent. Tang et al. (2017), for example, offered a multi-agent-based ETS simulation approach to test for a suitable carbon allowance auction design for the PRC's ETS and the authors concluded that the ETS has a substantial positive impact on reducing emissions and improving the energy structure. However, the authors advised that it has an adverse effect on economic growth. Likewise, Mu et al. (2018) document, using a CGE framework, that only the eight sectors that are planned as part of the initial execution of the ETS in the PRC are likely to have a much larger mitigation cost; however, the mitigation costs can be minimized by up to 3.3% of real GDP by 2030, but

only if other prominent energy-intensive sectors, which account for about an additional 24.8% of total emissions, are included in the ETS system.

Japan: The development of Japan's carbon market can be viewed in two different dimensions. First, the development of the CDM project, which took effect during the period 2002–2004 with 12 projects and two out of these 12 projects are in the validation process. The projects focus on the decomposition of carbon emissions, and the projects are estimated to have 4.8 million tonnes of CO₂ equivalent per year (Mizuno 2004). Secondly, the development of the Japanese Voluntary Emissions Trading Scheme (JVETS), which was introduced in 2005 by the Ministry of Environment, Japan (MOEJ), and is aimed at reducing the greenhouse gas emission (GHG) activities in the Japanese companies listed under the Keidanren Voluntary Action Plan (VAP) (MOEJ 2012). As of 2012, the JVETS had 389 members, which achieved a great reduction in their total emissions, i.e., 59,419 tCO₂. It was noted that the mean trading price was roughly JP¥ 216 (\$2.60)/tCO₂. In addition, the 389 companies that participated in the JVETS recorded a cumulative emissions decrease of 2,217 million tCO₂e; this was much higher than the planned target of 1,245 million tCO₂e. The JVETS increased further to cover 0.3% of the emissions in 1990 (3.4 million tCO₂/year as observed in the fourth term) (IGES, EDF, and IETA 2016).

Studies have analyzed the ETS linking in Japan. For example, Wakabayashi and Kimura (2018) point out that the Tokyo ETS alone cannot reduce carbon emissions, but has other factors such as energy saving tools. However, Lu et al. (2013) used a multi-regional model and found that the carbon leakage ratio in the case of full auctioning in the ETS of Japan is not very different from the GF (grandfathering) and OB (output-based) scenarios, and do not reduce carbon emissions.

Republic of Korea: In compliance with the Kyoto Protocol, in May 2012 the Government of the Republic of Korea passed “the Act on the Allocation and Trading of Greenhouse Gas Emission Permits”. But the implementation could not begin until 2014 with the establishment of the ETS's simple proposal and formulation of the First National Emission Permit Allocation Plan. At the beginning, the Ministry of the Environment decided to allocate about 1,598 million Korean allowance units (KAUs) to 525 companies for the year 2015 (IETA 2017). The allocation of credits was successfully completed in August 2016, which was part of the first phase in the first year of compliance.

The second phase of the Korean ETS was introduced in January 2018 and will run through until 2020 with an estimated emission cap of 538.5MtCO₂ to be considered as against 0.4 MtCO₂ less than the previous year as documented in the National Allocation Plan. At the beginning of 2019, auctioning was considered in the subsectors that failed to meet the standards for trade intensity and further production-related cost due to the ETS; and they are estimated at 3% of total volume of allowances which is auctioned to these subsectors. However, the other subsectors that meet the standards continue to obtain 100% free allocation (MoE, Republic of Korea 2018). Basically, in the second phase, free allocation is stretched to eight subsectors rather than the usual three subsectors, namely cement, refinery, and aviation. Moreover, guidelines have also been developed to allow the use of CERs generated outside the Republic of Korea for compliance.

4. THE POTENTIAL CHALLENGES FOR THE GROWTH OF CARBON MARKETS IN ASIA

Asia is one of the fastest-growing regions of the world. However, the region is also responsible for a major share of global emissions, particularly in the recent period. Therefore, in this section, we aim to highlight the challenges that the region is facing in order to address the issue of climate change without damaging its economic development and prosperity.

Inadequate implementation of ETS policy: Adequate policy implementation is indispensable, particularly when beginning to establish a carbon market. The reason for this is that the market relies heavily on it to boost outputs through its ETS policy by binding the emission cap that is set out to all firms that need to limit their GHG emissions, or by controlling the number of firms based on their commitment to reducing emissions. However, it is evident that such an emission cap in the Asian carbon market is yet to be introduced. Further, it is also important to highlight that the market demand is not strong enough to help the new industry meet its emission reduction targets.

This may be because the Asian carbon market is still very young and most countries in the region are in the first phase of its implementation. In the absence of full implementation of the ETS policy, it is well documented that most of the existing emissions trading systems do not cover all sectors and only a few major carbon emitters are included in the ETS policy (Mu et al. 2018). The ETS policy has been driven by chemicals, petrochemicals, iron and steel, construction materials, paper, air transport industries, nonferrous metals, and electricity. However, the wide sectoral coverage is to estimate the true picture of mitigation costs as compared with the limited sectoral design, which can underestimate the mitigation costs.

Limited private financing: It has been well argued that financial institutions play an important role in the functioning of the carbon market (UNEP 2011). This does not exclude Asia, where the major financing role is played by the banking sector. However, severe capital adequacy requirements and maturity mismatches have been attached to lending. According to Watson et al. (2017), 18 countries in Asia received a total of \$3.8 billion in climate funds from 17 multilateral climate funds and initiatives for 422 projects and programs in 2016. Among the funds are the PRC's public climate funds currently dominating the total investment in climate finance (Wang, Liu, and Chen 2012). An estimated \$294 billion was offered by state-owned banks in 2011 and the government climate spending was \$41 billion, while foreign and domestic bank loans stood at \$10 billion (The Climate Group 2013). Thus, it implies that the major source of climate finance is public funds. It is also important to highlight that the current system is not able to divert private investments into the carbon markets. However, this is in contrast to the global practice, where private investment is the major source of finance for climate mitigation (Stadelmann et al. 2013; Grubb et al. 2011).

Lack of regulatory system: Going by international standards in carbon-trading management systems there should be an integrated institutional setup in which the system takes control of regulating the carbon trading and its functioning. For instance, in the EU, the carbon-trading management system adopted a two-level organization, which includes central management and environmental protection departments from the governments of members (Knight 2010). Further, it clearly specifies the division of work, and an explicit distinction is drawn between rights and obligations. Moreover, it is also important to note that coordination and cooperation are also ensured to achieve high efficiency in the operation and management of the carbon-trading system.

However, this is not applicable in the Asian carbon market where no specific regulatory institution is responsible for the carbon trade setup. Because of that, it is difficult to set up a reliable and robust monitoring system, and reporting and authentication mechanisms, which remain the backbone to the success of the carbon market in Europe, and so the legal administration is continuously a problem that challenges all walks of life in the society. Hence, we highlight the fact that currently there is no regional-level regulatory system that helps to strengthen and make smooth the functioning of the emission trading system and ETS administrative operation. Although the ETS program has been implemented by the respective countries in the region, there is no harmonized system, and it is useful to review and adopt a more unified regulatory system for the region, which will play a key role in this aspect.

Corruption, access to information, and local capacity: Most of the Asian countries either operate a central economy or are in the phase of transiting to a market-driven economy. So efforts to attract foreign investors are always faced with problems of corruption and bureaucracy, including poor law enforcement and poor infrastructures, all of which may impact on the ease of doing business generally and executing CDM projects in these countries. In addition, information about CDM potentials is paramount in the carbon market, because it enhances the viability of the market, but this information is often not accessible. For example, Nguyen, Sousa, and Uddin (2010) argued that national potentials of renewable energy resources have not been investigated and are often not available to users. As such, it has deterred investors and developers from investing in the Viet Nam carbon market. As these barriers continue to linger, the awareness of CDM potentials among enterprises, the private sector, public entities, and NGOs is limited.

5. EVIDENCE FROM PREVIOUS STUDIES

As regards the existing international literature on carbon emission markets, we can reasonably divide it into two segments. One strand of the literature has analyzed the interactions between carbon and energy markets (see, for example, Mansanet-Bataller, Pardo, and Valor 2007; Alberola, Chevallier, and Chèze 2008; Fezzi and Bunn 2009; Hintermann 2010). These authors find that energy prices, i.e., oil, gas, coal, and electricity, are important driven factors for carbon futures prices of the EU carbon emission market in Phase I. Bredin and Muckley (2011) investigate the association between carbon and energy prices in Phase II using a cointegration method. Using the Dynamic Conditional Correlation GARCH model, Koenig (2011) and Chevallier (2012) provide evidence of the dynamics of correlations between carbon and energy markets.

Another strand of the literature has examined the link between the carbon and financial markets, both at a theoretical and at an empirical level. For example, Daskalakis, Psychoyios, and Markellos (2009) find that there are significant negative linkages between the EU carbon emission market and equity markets. Gronwald, Ketterer, and Trück (2011) employ the copula method and find a significant dependence between carbon and stock markets. Koch (2014) considers a multivariate GARCH model to analyze the price interactions among carbon, energy, and financial markets.

According to the seminal review paper by Babatunde, Begum, and Said (2017), recently there has been an increasing interest in investigating the climate change mitigation policies in the PRC, especially among academia. Research related to the PRC can be safely divided into three strands, according to the specific aspect the strand focuses on: the reduction of CO₂ emission intensity, the development of renewable energy, and estimation of the emissions peak.

There is a vast strand of literature that tries to investigate the impact and evaluation of the PRC's carbon intensity targets, especially using Computational General Equilibrium (CGE) models. In a notable proportion of this strand of literature, various optimization methods have been used to look for the optimal mitigation cost path given some carbon intensity targets, treating these carbon intensity targets as emission constraints. In the short run, a noteworthy example is Zhang et al. (2013), which has simulated the statistical and economic influences of the PRC's national emission intensity targets over the sample period from 2010 to 2015 for the 12th National Five-Year Plan in the PRC. To their surprise, they are only able to identify a considerable welfare loss, which ranges from about 1.2% to 1.5% via different disaggregation technologies of reduction targets among various Chinese provinces. In contrast, Dai et al. (2011) identified a much smaller (if not trivial) impact. According to the PRC's Copenhagen commitment, compared with its 2005 level, the PRC will try to reduce its national CO₂ emissions intensity by about 40%–45% before the end of 2020, and Dai et al. (2011) concluded that even in the extreme case where the PRC has successfully fulfilled its commitment (which is unlikely given the current situation that the PRC's carbon emissions were still relatively high by the end of 2016), the PRC's national GDP loss would only range from about 0.032% to 0.24%.

In the long run, Wang, Wang, and Chen (2009) tried to gauge the economic impact of the PRC's long-term emission reduction scenario up to 2050. In contrast to the extant literature, they argued that foreseen and unforeseen technological innovations may to some extent promote economic growth in the PRC, improve the energy efficiency in the country, and reduce the carbon intensity there. At the same time, Qi et al. (2016) also simulated a long-term scenario for the PRC from 2020 to 2050. They assumed a 3% average annual reduction in CO₂ intensity over their sample period, and they found that the associated national welfare loss in the PRC would be only 0.9% for the year 2030, which would increase to 1.6% for the year 2050. Taking into account the possible international/national/regional design of the associated carbon emission trading scheme (ETS) in the future, some other papers have also tried to gauge the economic impacts of carbon intensity targets in the PRC and obtained different results. For instance, assuming the existence of a counterfactual global carbon emission market, both Zhang et al. (2017) and Qi and Weng (2016) attempted to gauge the economic impact of the PRC's emission targets by the end of 2020 and by the end of 2030, respectively. At the same time, using the sectoral approach as a complement, Mu, Wang, and Cai (2017) went one step further and argued that the international Intended Nationally Determined Contributions (INDC) would be able to help achieve the committed emission reduction target without suffering from statistically significant economic loss. Focusing on one province (i.e., Guangdong) and assuming that the PRC will fully achieve its Copenhagen commitment, Wang et al. (2015) attempted to quantify the economic impacts of the ETS in one of the most developed provinces in the PRC (i.e., Guangdong province) by the end of 2020. At the same time, focusing on Shanghai city and assuming that the PRC's carbon intensity targets committed to the INDC will be fully achieved by the end of 2030, Wu et al. (2016) performed an empirical analysis that was very similar to that carried out by Wang et al. (2015). Both Wang et al. (2015) and Wu et al. (2016) identified a negative economic influence in the PRC brought about by achieving the PRC's emission reduction targets, and provided evidence that the carbon emission trading scheme is able to help mitigate the associated costs when the PRC moves towards its carbon emission reduction target.

There is another strand of literature that focuses on the social, economic, and environmental impacts of the development of renewable energy in the PRC, especially in last couple of decades. A notable example is Qi, Zhang, and Karplus (2014), who conjectured that the carbon emission reduction will not be substantial, in spite of the fact

that there is a possibility that there will be many additional renewable power installations in the second decade of the 21st century. Focusing on the impact on the employment rate, Cai et al. (2014) found empirical evidence that there would be more and more job creation due to the development of renewable and/or new energy in the PRC from the second decade of the 21st century. Interestingly, Dai et al. (2016) successfully found more encouraging evidence that the reduction of carbon emissions and upgradation will both be achieved without sacrifice in terms of substantial macroeconomic costs due to the large-scale development of renewable energy in the PRC. Taking into account the synergy between emission control and renewable/new energy, Mittal et al. (2016), Cheng et al. (2016), and Duan et al. (2016) provided more affirmative evidence that both the targets of carbon emission reduction and the development of renewable/new energy in the PRC may be achieved at the same time without suffering too much in terms of macroeconomic costs.

To sum up, the extant literature up till now has already documented a range of evidence on the ongoing smooth low-carbon transition of the Chinese economy and most of the evidence is encouraging for both economists and policy makers. However, there is still a gap in the literature, which is the interrelationship among the newly established regional carbon emission exchanges in the PRC, especially taking into account the exogenous impact from the well-established carbon emission exchanges from outside the PRC. Therefore, we are conducting this project to investigate the potentially existing interrelationship between arguably the two most important domestic carbon emission exchanges in the PRC, taking into account the probable exogenous impact from the influential European ETS.

6. DATA AND METHODOLOGY

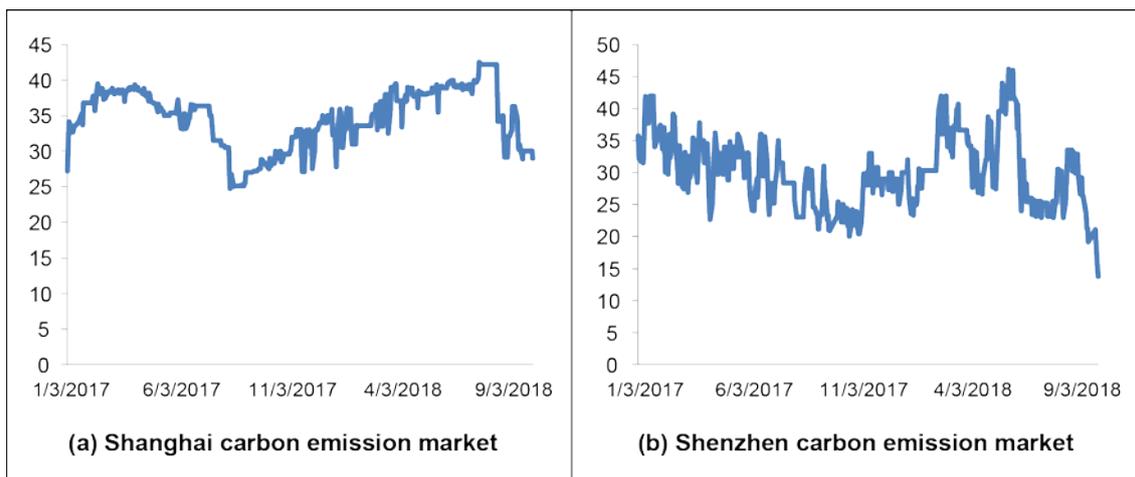
6.1 Data

This section provides a detailed description of the data. The data set consists of daily price for the EU carbon emission market (EU)¹, the Shanghai carbon emission market (SH), and the Shenzhen carbon emission market (SZ)² over the period from 3 January 2017 to 9 October 2018, since there were only trivial trading volumes in the Shanghai and Shenzhen carbon emission markets before 2017. All commodity prices are expressed in CNY. Figure 1 shows the time series plot for the closing prices in both the Shanghai and Shenzhen carbon emission markets in terms of daily frequency. According to Figure 1, there are enough sample variations for both the Shanghai and Shenzhen carbon emission markets over our sample period in our data set. Interestingly, there is no clear time trend in the Shanghai carbon emission market, while there is to some extent a declining time trend in the Shenzhen carbon emission market. We present the summary statistics in Table 1 and Table 2 further supports our previous observation that there are enough sample variations for both the Shanghai and Shenzhen carbon emission markets over our sample period in our data set.

¹ Historical Futures Prices: ECX EUA Futures, Continuous Contract #1. Nonadjusted price based on spot-month continuous contract calculations. Raw data from ICE.

² We consider the main contract SZA-2016 in the Shenzhen carbon market.

Figure 1: Daily Closing Prices



Note: This figure displays the time series of the futures prices in the first and second commitment periods in the Shanghai carbon emission market and the Shenzhen carbon emission market (from 3 January 2017 to 9 October 2018) in subfigure (a) and subfigure (b), respectively. To construct a continuous series of futures prices, the futures contracts switch over on the first day of a new month's trading, for all available trading months. The horizontal axis is dates, while the vertical axis is the futures prices.

Table 1: Descriptive Statistics of the Selected Variables (After Logarithm)

Variable	Minimum	Maximum	Mean	Std Dev
EU	3.482564	5.299405	4.175204	0.515983
SH	3.208825	3.749975	3.540342	0.127661
SZ	2.941804	3.832980	3.389923	0.179254

Note: This table presents the descriptive statistics of the main variables in the paper.

Table 2: Unit Root Test Results

Variable	ADF Unit Root Test	Phillips-Perron (PP) Unit Root Test
In levels		
EU	-1.1522	-1.8257
SH	-1.5387	-2.5868
SZ	-3.5543***	-4.3637***
In first-order difference		
EU	-7.2938***	-21.984***
SH	-8.2219***	-19.829***
SZ	-9.7686***	-23.093***

Note: This table presents the results from two unit root tests (i.e., the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests), while *, **, and *** indicate the significance at the 10%, 5%, and 1% level, respectively.

To begin our investigation, it is necessary to test the stationarity of the variables used in this analysis. To determine the order of the stationarity of these series, we consider both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The results in Table 2 show mixed findings. The null hypothesis that there is a unit root in levels cannot be rejected for the EU and SH markets but not for the SZ market at 1% significance level. However, the null hypothesis that there is a unit root in levels is strongly rejected at the 1% significance level for all variables when they are applied to

the first-order differences. These findings indicate that our variables have a mixed order of integration and that EU and SH are I (1) and SZ is I (0), which makes our empirical analysis more difficult and hinders many common econometric tools in this project.

6.2 Methodology

One of the aims of this study is to investigate the relationship between the PRC's carbon emission markets, and between the EU and the PRC's carbon emission markets. Due to the mixed order of integration of our data, we employ the autoregressive distributed lag (ARDL) approach (see, for example, Pesaran, Shin, and Smith 2001) to investigate the impact of the EU carbon emission market on the PRC's carbon emission markets. The autoregressive distributed lag model assumes that the dependent variable is a function of its own past lagged values as well as current and past values of other explanatory variables. For the autoregressive distributed lag model, the sample series do not have to be I (1) (see, for example, Pesaran and Pesaran 1997). In addition, the autoregressive distributed lag model in conditional EC form can integrate short-run adjustment effects with long-run equilibrium without losing information (see, for instance, Jalil and Feridun 2011). Therefore, we can get more information, especially in terms of efficient cointegration relationships, by using the autoregressive distributed lag approach (see, for instance, Ghatak and Siddiki 2001). The autoregressive distributed lag (p, q) model can be specified as follows:

$$y_t = a + \sum_{i=1}^p \varphi_i y_{t-i} + \sum_{i=0}^q \delta_{1i} x_{1,t-i} + \sum_{i=0}^r \delta_{2i} x_{2,t-i} + \varepsilon_t$$

where $t = \max(p, q, r), \dots, T$. The optimal lag orders p , q , and r can be obtained by minimizing the conventional Bayesian information criterion (BIC). For most cases, we find that the optimal number of lags is $t = 1$, which we use in the analysis. As a result, we restrict all of them that equal one to reduce the noise introduced by the optimal number of lags, and make sure that each term is on the same page.

To better investigate the direction of the long-run relationship between the Shanghai carbon emission market and the Shenzhen carbon emission market in the PRC, we reparametrize the above autoregressive distributed lag model in conditional EC form, which is as follows:

$$\begin{aligned} \Delta \ln SH_t &= a + \sum_{i=1}^{p-1} \alpha_i \Delta \ln SH_{t-i} + \sum_{i=0}^{q-1} \beta_i \Delta \ln EU_{t-i} + \sum_{i=0}^{r-1} \rho_i \Delta \ln SZ_{t-i} \\ &\quad - \gamma (\ln SH_{t-1} - \theta_1 \ln EU_{t-1} - \theta_2 \ln SZ_{t-1}) + \varepsilon_t \\ \Delta \ln SZ_t &= a + \sum_{i=1}^{p-1} \alpha_i \Delta \ln SZ_{t-i} + \sum_{i=0}^{q-1} \beta_i \Delta \ln EU_{t-i} + \sum_{i=0}^{r-1} \rho_i \Delta \ln SH_{t-i} \\ &\quad - \gamma (\ln SZ_{t-1} - \theta_1 \ln EU_{t-1} - \theta_2 \ln SH_{t-1}) + \varepsilon_t \end{aligned}$$

where $\gamma = 1 - \sum_{i=1}^p \varphi_i$ and the long-run coefficients $\theta_1 = \frac{\sum_{i=0}^q \delta_{1i}}{\gamma}$ and $\theta_2 = \frac{\sum_{i=0}^r \delta_{2i}}{\gamma}$. In these two formulas above, the shortened forms SH, SZ, and EU stand for futures prices in the Shanghai carbon emission market, the Shenzhen carbon emission market, and the EU carbon emission market, respectively. These forms of equations provide us with an opportunity to look into both the short-run and long-run relationship at the same time. It is also feasible to include more control variables if necessary.

7. EMPIRICAL RESULTS AND DISCUSSION

This section presents the results obtained via the model specified in the previous section. In this section, we will empirically examine the impact of the EU carbon emission market on the PRC's carbon emission markets. The main results of our autoregressive distributed lag model are displayed in Tables 3 and 4. Several conclusions can be drawn from these two tables. The most important one is perhaps regarding the interrelationship in the long run as indicated below:

- According to Panel A in Table 3, a 1% growth in the futures price in the Shanghai carbon emission market increases the futures price in the Shenzhen carbon emission market by 0.5502% in the long run, which is strongly statistically significant at the 5% level.
- According to Panel A in Table 4, a 1% increase in the futures price in the Shenzhen carbon emission market raises the futures price in the Shanghai carbon emission market by 0.4330% in the long run, which is only marginally statistically significant at the 10% level.

The above findings indicate that there is a (at least unidirectional) long-run relationship between the Shanghai carbon emission market and the Shenzhen carbon emission market in the PRC. More specifically, the long-run results for the Shenzhen carbon emission market (Panel A in Table 3) show that the Shanghai carbon emission market plays a substantial role in promoting the futures price in the Shenzhen carbon emission market, which is generally positive as expected. In contrast, the EU carbon emission market is not found to have a statistically significant long-run impact on the Shenzhen carbon emission market. However, the long-run results for the Shenzhen carbon emission market (Panel A in Table 4) reveal that the Shenzhen carbon emission market is not a statistically significant determinant of the Shanghai carbon emission market at the conventional 5% significance level.

**Table 3: Estimated Autoregressive Distributed Lag Model,
Long-run and Short-run Coefficients
(Dependent Variable: $\ln SZ$, Autoregressive Distributed Lag (1, 5, 1))**

Variable	Estimate	Std. Err	Z Value	Pr(>z)
Panel A: Long-run Coefficients				
$\ln EU$	-0.0262	0.0250	-1.0460	0.2956
$\ln SH$	0.5502**	0.2406	2.2870	0.0222
Panel B: Short-run Coefficients				
(Intercept)	1.4073***	0.3346	4.2060	0.0000
$L. \Delta \ln SZ$	-0.0483	0.0492	-0.9810	0.3270
$\Delta \ln EU$	-0.0349	0.0395	-0.8840	0.3760
$\Delta \ln SH$	0.0081	0.0996	0.0820	0.9350
$ecm(-1)$	-0.1102***	0.0241	-4.5710	0.0000

Note: This table reports the estimated coefficients from the autoregressive distributed lag model. The dependent variable is $\ln SZ$. Std.Err denotes the standard error, while Pr(>z) denotes the p value. The appropriate lag length was selected based on the BIC, while *, **, and *** indicate the significance at the 10%, 5%, and 1% level, respectively.

To our surprise, the long-run impact of the EU carbon emission market on the Shanghai and Shenzhen carbon emission markets is also not statistically significant at the conventional 5% significance level. To be specific, for the Shenzhen carbon emission market the estimated coefficient for $\ln EU$ is -0.0262 with a p value of 0.2956 in Panel A of Table 3, and for the Shanghai carbon emission market the estimated coefficient for $\ln EU$ is 0.0035 with a p value of 0.9202 in Panel A of Table 4.

**Table 4: Estimated Autoregressive Distributed Lag Model,
Long-run and Short-run Coefficients
(Dependent Variable: $\ln SH$, Autoregressive Distributed Lag (3, 1, 1))**

Variable	Estimate	Std. Err	Z Value	Pr(>z)
Panel A: Long-run Coefficients				
$\ln EU$	0.0035	0.0349	0.1000	0.9202
$\ln SZ$	0.4340*	0.2620	1.6560	0.0977
Panel B: Short-run Coefficients				
(Intercept)	1.0645***	0.3188	3.3390	0.0008
$L. \Delta \ln SH$	0.0567	0.0483	1.1740	0.2403
$\Delta \ln EU$	-0.0109	0.0193	-0.5630	0.5733
$\Delta \ln SZ$	0.0035	0.0235	0.1470	0.8831
$ecm(-1)$	-0.0498 ***	0.0146	-3.3990	0.0007

Note: This table reports the estimated coefficients from the autoregressive distributed lag model. The dependent variable is $\ln SH$. Std.Err denotes the standard error, while $Pr(>z)$ denotes the p value. The appropriate lag length was selected based on the BIC, while *, **, and *** indicate the significance at the 10%, 5%, and 1% level, respectively.

The short-run coefficients are shown in Panel B of Tables 3 and 4. The short-run impact of the EU carbon emission market is also not statistically significant on either Shanghai or Shenzhen carbon emission market at the conventional 5% significance level. To be specific, for the Shenzhen carbon emission market the estimated coefficient for $\Delta \ln EU$ is -0.0349 with a p value of 0.3760 in Panel B of Table 3, and for the Shanghai carbon emission market the estimated coefficient for $\Delta \ln EU$ is -0.0109 with a p value of 0.5733 in Panel B of Table 4. The reason may be due in part to the characteristics of regional trading for carbon emission markets in the PRC, which lead to the strong linkage between the Shenzhen and Shanghai carbon emission markets in the PRC and the insignificant impact of the EU carbon emission market on both the Shenzhen and Shanghai carbon emission markets in the PRC.

The short-run coefficients for the key variables are not statistically significant at the conventional 5% significance level, which indicates that the short-term fluctuations in the Shenzhen and Shanghai carbon emission markets are irrelevant to each other. To be specific, for the Shenzhen carbon emission market the estimated coefficient of $\Delta \ln SH$ in Table 3 is -0.0483 with a p value of 0.3270, while for the Shanghai carbon emission market the estimated coefficient of $\Delta \ln SZ$ in Table 4 is 0.0035 with a p value of 0.8831. Moreover, in both equations, the estimated coefficient of the error correction term (i.e., $ecm(-1)$ in Table 3 and Table 4) is statistically significant at the 1% significance level and negative. To be specific, the estimated coefficient of $ecm(-1)$ is -0.1102 and -0.0498 in Table 3 and Table 4, respectively. This negative estimated coefficient of the error correction term implies the speed of adjustment at which a dependent variable returns to equilibrium following a change in the long-run equilibrium relationship (see, for example, Sari, Ewing, and Soytaş 2008). What is more, the results show that the futures price in

the Shenzhen carbon emission market, with a larger (in absolute magnitude) estimated coefficient of the error correction term (i.e., $ecm(-1)$ in Table 3 and Table 4), has a faster adjustment rate than the futures price in the Shanghai carbon emission market.

Given the above findings, we argue that there is no significant short-run relationship between the Shanghai and Shenzhen carbon emission markets, but they will influence each other from the standpoint of their long-run relationship. Hence, we suggest that policy makers and government officials can enhance the long-term carbon emission market cooperation and linkage in the PRC to progressively deepen the domestic emissions trading system.

Finally, we explore the short-run causalities between the futures prices in the Shanghai and Shenzhen carbon emission markets using the Granger causality test. The results of these short-run causalities are shown in Table 5. The research results indicate that there is no reverse causality between the Shanghai and Shenzhen carbon emission markets at the conventional 5% statistical significance level, but there is a bidirectional relationship between the Shanghai and Shenzhen carbon emission markets at the 10% statistical significance level. For instance, the p value for rejecting the null hypothesis that the futures prices in SZ do not Granger-cause the futures prices in SH is 0.06766, while the p value for rejecting the null hypothesis that the futures prices in SH do not Granger-cause the futures prices in SZ is 0.05761.

Table 5: Short-run Granger Causalities

Null Hypothesis	F-test Statistic	Prob.
The future prices in SZ do not Granger-cause the future prices in SH	0.7870	0.5017
The future prices in SH do not Granger-cause the future prices in SZ	1.3967	0.2486

Note: This table reports the short-run Granger causalities using one lag in the estimation. We use *, **, and *** to denote the significance at the 10%, 5%, and 1% level, respectively.

8. CONCLUDING REMARKS WITH POLICY IMPLICATIONS

In this paper, we explore the interrelationship between the Shanghai and Shenzhen carbon emission markets, using an autoregressive distributed lag model with daily high-frequency data from 3 January 2017 to 9 October 2018. This form of equation provides us with an opportunity to look into both the short-run and long-run relationship at the same time. It is also feasible to include more control variables if necessary. Using this approach, we provide several new findings. First, we show that in the long run there is a unidirectional influence from the futures prices in the Shanghai carbon emission market on the futures prices in the Shenzhen carbon emission market, but not in the other direction. This is statistically significant at the 1% level and the magnitude is very large. Second, we find a marginal significant short-run influence from the futures prices in the Shanghai carbon emission market on the futures prices in the Shenzhen carbon emission market, and from the futures prices in the Shenzhen carbon emission market on the futures prices in the Shanghai carbon emission market. Finally, to our surprise, in both the long run and short run we find that the futures prices in the EU ETS market have a very insignificant impact on the futures prices in both the Shanghai and Shenzhen carbon emission markets.

These findings have three important implications. First, our results shed light on the carbon emission markets' policy formulation for the Chinese government to achieve sustainable economic growth and meet carbon reduction targets in the PRC. Second, our results suggest that the carbon emission markets are to a very large extent segmented at the international level, which calls for international cooperation in terms of reducing carbon emission targets. Third, the identification of a significant long-run relationship but only a marginally significant short-run relationship suggests that even at the national level the domestic carbon emission exchanges in the PRC are to some extent segmented, which suggests that a unified carbon emission trading system should be put into effect as soon as possible.

We have to admit that there are some limitations to this study. Ideally, we should have relied on a well-accepted economic theory to investigate the interrelationship between the Shanghai and Shenzhen carbon emission markets. Without such a theory, we propose using an autoregressive distributed lag model with daily high-frequency data from 3 January 2017 to 9 October 2018. The choice of carbon emission exchanges is somewhat arbitrary, as we simply choose arguably the two most famous ones, in parallel to the well-established stock trading exchanges in the PRC. Of course, more exogenous variables may be added. However, we doubt that our key results will change, due to the robust nature of our methodology. We believe that it is a fruitful research direction and leave it for future projects.

Further, we make a number of policy recommendations in regard to the efficient functioning of the ETS in the Asia region with special reference to the PRC, due to its significant contribution to global emissions. More specifically, we suggest that there are a number of barriers in the Asia region, particularly the fact that there is a little support for the carbon market. Therefore, it is important to establish a strong regulatory system that should aim to strengthen and support the functioning of the emission trading system in the region, and perhaps across the major economies. Policy makers and government officials should also give considerable attention to encouraging private investments into the carbon market and there is also a need to support public–private partnership investments into clean energies and energy-efficient technologies, which will have a greater impact on climate change management (Kutan et al. 2018; Paramati, Ummalla, and Apergis 2016; Paramati, Apergis, and Ummalla 2017). Policy makers, with the cooperation of governments, should aim to improve the functioning of the bureaucracy, particularly the departments that are directly and indirectly linked with climate change initiatives. All these additional policy initiatives will have a greater impact on the functioning and performance of the ETS in the region, as well as in the PRC.

REFERENCES

- Alberola, E., Chevallier, J., and Chèze, B. 2008. Price drivers and structural breaks in European carbon prices 2005–2007. *Energy Policy*, 36(2): 787–797.
- Babatunde, K., Begum, R., and Said, F. 2017. Application of computable general equilibrium (CGE) to climate change mitigation policy: a systematic review. *Renew Sustain Energy Review*, 78: 61–71.
- Bredin, D., and Muckley, C. 2011. An emerging equilibrium in the EU emissions trading scheme. *Energy Economics*, 33: 353–62.
- Cai, W., Mu, Y., Wang, C., and Chen, J. 2014. Distributional employment impacts of renewable and new energy: A case study of China. *Renew Sustain Energy Review*, 39: 1155–63.
- Cheng, B., Dai, H., Wang, P., et al. 2016. Impacts of low-carbon power policy on carbon mitigation in Guangdong Province, China. *Energy Policy*, 88: 515–27.
- Chevallier, J. 2009. Carbon futures and macroeconomic risk factors: a view from the EU ETS. *Energy Economics*, 31(4): 614–625.
- . 2012. Time-varying correlations in oil, gas and CO₂ prices: an application using BEKK, CCC and DCCMGARCH models. *Applied Economics*, 44, 4257–4274.
- Dai, H., Masui, T., Matsuoka, Y., et al. 2011. Assessment of China's climate commitment and non-fossil energy plan towards 2020 using hybrid AIM/CGE model. *Energy Policy*, 39: 2875–87.
- Dai H., Xie, X., Xie, Y., et al. 2016. Green growth: the economic impacts of large-scale renewable energy development in China. *Applied Energy*, 162: 435–49.
- Daskalakis, G., Psychoyios, D., and Markellos, R. N. 2009. Modeling CO₂ emission allowance prices and derivatives: evidence from the European trading scheme, *Journal of Banking and Finance*, 33, 1230–1241.
- Duan, H., Zhang, G., Zhu, L., et al. 2016. How will diffusion of PV solar contribute to China's emissions-peaking and climate responses?. *Renew Sustain Energy Review*, 53: 1076–1085.
- EDF. 2017. 2017 Progress of China 's carbon market. <https://www.edf.org/report-eu-emissions-trading-system>.
- EU, 2017. Commission Regulation (EU) No 550/2011 of 7 June 2011 on Determining, Pursuant to Directive 2003/87/EC of the European Parliament and of the Council, Certain Restrictions Applicable to the Use of International Credits from Projects Involving Industrial Gases. *Official Journal of the European Union*. Brussels: European Union. <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011R0550&from=EN>.
- Ewing, J. 2016a. *Roadmap to a Northeast Asian Carbon Market*. Asia Society Policy Institute, September.
- . 2016b. Time to Link Northeast Asia's Carbon Markets. Retrieved from www.thediplomat.com/2016/06/time-to-link-northeast-asias-carbon-markets.
- Fankhauser, S. 2011. Carbon Trading: A good idea is going through a bad patch. *The European Financial Review*, 32-35.
- Fezzi, C., and Bunn, D. W. 2009. Structural interactions of European carbon trading and energy prices, *Journal of Energy Markets*, 2: 53–69.

- Ghatak, S., and Siddiki, J. 2001. The use of autoregressive distributed lag approach in estimating virtual exchange rates in India. *Journal of Applied Statistics*, 28: 573–583.
- Government of the PRC. 2017. China-Canada Joint Statement on Climate Change and Clean growth. <http://www.china-embassy.org/eng/zgyw/t1516436.htm>.
- Gronwald, M., Ketterer, J. and Trück, S., 2011. The relationship between carbon, commodity and financial markets: A copula analysis. *Economic record*, 87, pp.105–124.
- Grubb, M. 2012. Emissions trading: Cap and trade finds new energy. *Nature*, 491(7426), 666.
- Grubb, M., Laing, T., Counsell, T., and Willan, C. 2011. Global carbon mechanisms: lessons and implications. *Climatic Change*, 104(3–4), 539–573.
- Guan, D., and Hubacek, K. 2010. China can offer domestic emission cap-and-trade in post 2012. *Environmental Science and Technology*, 44(14), 5327–5327. doi: 10.1021/es101116k.
- Hartmann, T. 2017. How does Carbon Trading Work? Retrieved from www.weforum.org/agenda/2017/09/everything-you-need-to-know-about-carbon-trading/.
- Hintermann, B. 2010. Allowance price drivers in the first phase of the EU ETS. *Journal of Environmental Economics and Management*, 59: 43–56.
- IETA. 2015. Republic of Korea: An Emissions Trading Case Study. 2015. Available online: http://www.ieta.org/resources/2016%20Case%20Studies/Korean_Case_Study_2016.pdf.
- . 2017. Assessing Singapore's carbon tax. Greenhouse Gas Market Emission Report 2017
- IGES, EDF and IETA. 2016. Japan: Market-based climate policy case study at www.iges.or.jp.
- Jalil, A., and Feridun, M. 2011. The impact of growth, energy and financial development on the environment in China: a cointegration analysis. *Energy Economics*, 33(2): 284–291.
- Jotzo, F., De Boer, D., and Kater, H. (2013). China Carbon Pricing Survey 2013, Working Papers 249409, Australian National University, Centre for Climate Economics & Policy.
- Koch, N. 2014. Dynamic linkages among carbon, energy and financial markets: a smooth transition approach. *Applied Economics*, 46(7): 715–729.
- Koenig, P. 2011. Modelling correlation in carbon and energy markets, EPRG Working Paper 1107. Electricity Policy Research Group, Cambridge.
- Knight, E. R. 2010. The economic geography of European carbon market trading. *Journal of Economic Geography*, 11(5), 817–841.
- Kramer, B., and Fraser-Hidalgo, D. 2018. Benefits of Carbon Pricing Outweigh the Costs. *Energy and Environment*, The Hill Boundless. Retrieved from <http://www.thehill.com/opinion/energy-environment/387126-benefits-of-carbon-pricing-outweigh>.

- Kutan, A. M., Paramati, S. R., Ummalla, M., and Zakari, A. 2018. Financing renewable energy projects in major emerging market economies: evidence in the perspective of sustainable economic development. *Emerging Markets Finance and Trade*, 54(8): 1761–1777.
- Lu, X., Asuka, J., Monjon, S., and Quirion, P. 2013. Analyses of impacts of ETS on industries in Japan. 16th Annual Conference on Global Economic Analysis, June, 2013.
- Mansanet-Bataller, M., Pardo, A., and Valor, E. 2007. CO2 prices, energy and weather. *Energy Journal*, 28: 73–92.
- Mizuno, J. 2004. The clean development mechanism: Current activities of Japan. *International Review for Environmental Strategies*, 5(1): 301–310.
- Ministry of Environment, Japan. 2012. Consideration of Emission Trading Scheme in Japan. https://www.env.go.jp/en/earth/ets/mkt_mech/scheme-emissions_trading.pdf.
- Ministry of Environment, Republic of Korea (2018). Emission Trading Scheme in Korean. Ministry of Environment Report 2018.
- Mittal, S., Dai, H., Fujimori, S., et al. 2016. Bridging greenhouse gas emissions and renewable energy deployment target: comparative assessment of China and India. *Applied Energy*, 166: 301–313.
- Mu, Y., Wang, C., and Cai W. 2017. Using sectoral approach as complement to the INDC framework: an analysis based on the CGE model. In: Proceedings of the 8th International Conference on Applied Energy – ICAE2016. *Energy Procedia*, 105: 3433–3439.
- Mu, Y., Evans, S., Wang, C., and Cai, W. 2018. How will sectoral coverage affect the efficiency of an emissions trading system? A CGE-based case study of China. *Applied Energy*, 227: 403–414.
- Nguyen, D.K., Sousa, R.M., Uddin, G.S. 2010. Testing for asymmetric causality between U.S. equity returns and commodity futures returns. *Finance Res. Lett.* 12(0), 38–47.
- Paramati, S. R., Apergis, N., and Ummalla, M. 2017. Financing clean energy projects through domestic and foreign capital: The role of political cooperation among the EU, the G20 and OECD countries. *Energy Economics*, 61, 62–71.
- Paramati, S. R., Ummalla, M., and Apergis, N. 2016. The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies. *Energy Economics*, 56: 29–41.
- Perdan, S., and Azapagic, A. 2011. Carbon trading: Current schemes and future developments. *Energy Policy*, 39(10), 6040-6054. doi: 10.1016/j.enpol.2011.07.003.
- Pesaran, M. H., and Pesaran, B. 1997. *Working with Microfit 4.0*. Camfit Data Ltd, Cambridge.
- Pesaran, M. H., Shin, Y., and Smith, R. J. 2001. Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16: 289–326.
- Qi T., and Weng, Y. 2016. Economic impacts of an international carbon emission market in achieving the INDC targets. *Energy*, 109: 886–893.

- Qi, T., Winchester, N., Karplus, V., et al. 2016. An analysis of China's climate policy using the China-in-Global energy model. *Economic Modelling*, 52(B):650–60.
- Qi, T., Zhang, X-L., and Karplus, V. 2014. The energy and CO2 emissions impact of renewable energy development in China. *Energy Policy*, 68: 60–69.
- Raitzer, D. A., Bosello, F., Tavoni, M., Orecchia, C., Marangoni, G., and Samson, J. N. G. 2015. *South East Asia and the Economics of Global Climate Stabilization*. Asian Development Bank.
- Sari, R., Ewing, B.T. and Soytas, U. 2008. The relationship between disaggregate energy consumption and industrial production in the United States: an ARDL approach. *Energy Economics*, 30(5), pp.2302–2313.
- Stavins, R. N. 2008. A meaningful US cap-and-trade system to address climate change. *Harv. Envtl. L. Rev.*, 32, 293.
- Stadelmann, M., Michaelowa, A., and Roberts, J. T. 2013. Difficulties in accounting for private finance in international climate policy. *Climate Policy*, 13, 718–737. doi:10.1080/14693062.2013.791146.
- Tang, L., Shi, J., and Bao, Q. 2016. Designing an emissions trading scheme for China with a dynamic computable general equilibrium model. *Energy Policy*, 97: 507–520.
- Tang, L., Wu, J., Yu, L., and Bao, Q. 2017. Carbon allowance auction design of China's emissions trading scheme: a multi-agent-based approach. *Energy Policy*, 102: 30–40.
- Taschini, L., Dietz, S., and Hicks, N. 2013. Carbon Tax versus Cap-and-Trade: Which is Better? *The Guardian.Np, nd Web*, 9.
- The Climate Group. 2013. *Shaping China's climate finance policy*. London: The Climate Group.
- The Economist. 2015. *Development and the Environment: China Wants to Clear the air with a market-based approach to pollution*. Accessed online.
- UNEP Finance Initiative. 2011. *Reddy-Set-Grow: Opportunities, Risk and Roles for Financial Institutions in Forest-Carbon Markets* Retrieved from <http://www.unespfi.org/events/climate-change-events/reddy-set-grow-opportunities-risks-and-roles-for-financial-institutions-in-forest-carbon-markets/>.
- Wakabayashi, M., and Kimura, O. 2018. The impact of the Tokyo Metropolitan Emissions Trading Scheme on reducing greenhouse gas emissions: findings from a facility-based study. *Climate Policy*, 18(8), 1028–1043.
- Wang, Q. 2013. China has the capacity to lead in carbon trading. *Nature*, 493, 273.
- Wang, P., Dai, H., Ren, S-Y., et al. 2015. Achieving Copenhagen target through carbon emission trading: economic impacts assessment in Guangdong Province of China. *Energy*, 79: 212–227.
- Wang, Y., Liu, Q., and Chen, B. 2012. *China climate finance report: climate capital flow*. Beijing: Central University of Finance and Economics and The Climate Group.
- Wang, K., Wang, C., and Chen, J-N. 2009. Analysis of the economic impact of different Chinese climate policy options based on a CGE model incorporating endogenous technological change. *Energy Policy*, 37: 2930–2940.

- Watson, C., Bird, N., Schalatek, L., and Keil, K. 2017. Climate finance fundamentals 8: Asia. Available at <http://www.odi.org/publications/11058-climate-finance-fundamentals-8-asia-2017-update>.
- World Bank. 2014. *State and Trends of Carbon Pricing*, Washington D.C. Available at <http://documents.worldbank.org/curated/en/2014/05/19572833/state-trends-carbon-pricing-2014>.
- Wu, R., Dai, H., Geng, Y., et al. 2016. Achieving China's INDC through carbon cap-and-trade: insights from Shanghai. *Applied Energy*, 184: 1114–1122.
- Zhang, D., Rausch, S., Karplus, V., et al. 2013. Quantifying regional economic impacts of CO2 intensity targets in China. *Energy Economics*, 40: 687–701.
- Zhang, X., Qi, T. Y., Ou, X. M., and Zhang, X. L. 2017. The role of multi-region integrated emissions trading scheme: a computable general equilibrium analysis. *Applied Energy*, 185: 1860–1868.
- Zhang, Y. J., Wang, A. D., and Tan, W. 2015. The Impact of China's Carbon Allowance Allocation Rules on the Product Prices and Emission Reduction Behaviors of ETS-Covered Enterprises. *Energy Policy*, 86, 176–185.