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China's Carbon Emissions from Fossil Fuels and Market-Based Opportunities for Control

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Abstract

In this article, we first review the history of carbon dioxide (CO_2) emissions from the combustion of fossil fuels for the People's Republic of China (China). As Chinese regulators have announced efforts to directly regulate CO_2 emissions, we review the history of institutions charged with climate regulation in China. Next we review China's existing market-based approaches to emission control in the form of the world's largest effluent fee system for air and water pollutants as well as seven pilot carbon markets. We conclude with a discussion of the issues and challenges ahead in adopting market-based instruments to regulate CO_2 emissions in China.

1. INTRODUCTION

In 1992, 255 nations met in Rio de Janeiro for the first Earth Summit to address the issue of sustainable development. One of the major outcomes of the summit was the United Nations Framework Convention on Climate Change (UNFCCC). The objective of the treaty was "to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (**http://unfccc.int/essential_background/convention/items/6036.php**). The framework ultimately led to the 1997 Kyoto Protocol, which went into force in February 2005. The two biggest emitters of greenhouse gases (GHGs), the United States of America and the People's Republic of China (China), had signed the UNFCCC, yet of the two only China signed and ratified the Kyoto Protocol. However, this only current global accord limiting GHG emissions does not require reductions from either country, as China signed on as an Annex B country, which exempts it from a binding emission reduction commitment. Twenty-two years have passed since the Rio Earth Summit. Annual global emissions of carbon dioxide (CO_2) from fossil fuel combustion have increased by 55% since then (BP 2014). Emissions by the United States have increased by 8.9% since 1990, whereas emissions by China have increased by 298% over the same time period. In 1990, the average US citizen was responsible for 10.5 times the GHG emissions of the average Chinese citizen. The gap in per capita terms is shrinking rapidly. China's per capita emissions are almost equivalent to those of the European Union. In 2013, the average American emitted "only" 2.7 times that of the average Chinese person.

In this article, we briefly review the emission trajectory of China, updating some of the data in the excellent review by Levine & Aden (2008) in the *Annual Review of Environment and Resources*. In our review, the data are limited to CO_2 emissions from the combustion of fossil fuels, as this source represents the majority of the growth in historical and anticipated emissions. The second part of the article reviews the institutions responsible for GHG mitigation and their evolution within the Chinese government. The third portion of the article provides an overview of the current market-based pollution control instruments used in China. The final section provides a discussion of the opportunities for controlling GHG emissions via market-based instruments going forward.

2. EXAMINING HISTORICAL EMISSIONS

2.1. Emission Trajectory

CO_2 emissions are almost never directly measured but are instead calculated mostly on the basis of fossil fuel consumption (Boden et al. 2013). The most complete global- and national-level record of CO_2 emissions from fossil fuel combustion is provided by the Carbon Dioxide Information Analysis Center (**http://cdiac.ornl.gov/**). More recent data are available from BP (2014).

During the last few years of the Qing Dynasty (1644–1912), China's CO_2 emissions were 0.31% of what they are today. During the Republic of China years (1912–1949), emissions grew 5% per year. The first recorded noncoal emissions appeared in 1926 in the form of liquid fuels. By 1949, coal still accounted for 99% of China's CO_2 emissions. During the period under Chairman Mao (1949–1976), emissions grew 11% per year, which resulted in a 15-fold increase in emissions. During this period, the share of coal fell to 76%, and the share of liquid fuels rose to 20%. To put these figures into a broader perspective, China's total emissions in 1976 were equal to roughly 12.5% of its emissions in 2013. After Chairman Mao's passing, which was followed by years of early market reform from 1977 to 1999, emissions grew by 4.4% per year, resulting in total year 1999 emissions of 35% of what they are today. At 72% in 1999, coal's emission share was only slightly lower than at the time of Mao's passing, and the share of liquids had also not substantially changed. During the years 2000–2004, the growth rate of emissions surged to 12.9% p.a. (per annum), with essentially unchanged shares of emissions from coal and liquids. Since 2004, emissions have grown at an annual rate of 6.9%, with roughly 70% of emissions still coming from coal. China became the world's leading CO_2 emitter sometime in late 2006 and by 2011 had more emissions from CO_2 from coal alone than the total emissions from all fuels by the second-largest emitter—the United States.

Figure 1 compares, for these two largest emitters, the trajectory of emissions from coal, liquid fuels, and gas. There are some noteworthy differences in the two trajectories. First, at the beginning of the twentieth century, both US and Chinese emissions came almost exclusively from coal. However, by the end of World War II, the US share of emissions from coal fell to 61% compared with China's 98% share. In the United States, 30% of emissions shifted to liquid sources, with another 9% to gas. The contrast is still sharp today. In the United States, 35% of emissions come from coal, 40% from liquid fuels, and an impressive and growing 24% from gas. In China, this composition is heavily skewed toward coal (72%) rather than to liquids (14%) or gas (3%). Significantly, 11% of Chinese emissions are attributed to the production of cement, which is an order of magnitude higher than the US share. If we compare US and Chinese emissions with global average emissions, the world emission profile looks more like that of the United States than it does like that of China. Globally, coal accounted for 43% of global emissions, liquid fuels for 34%, and gas combustion for 18%. The manufacture of cement accounts for 5% globally and the flaring of natural gas for 1%.

As emission data are not based on measurements but are rather calculated on the basis of fuel use, the emission data are only as good as the fuel use data. The two main sources of measurement

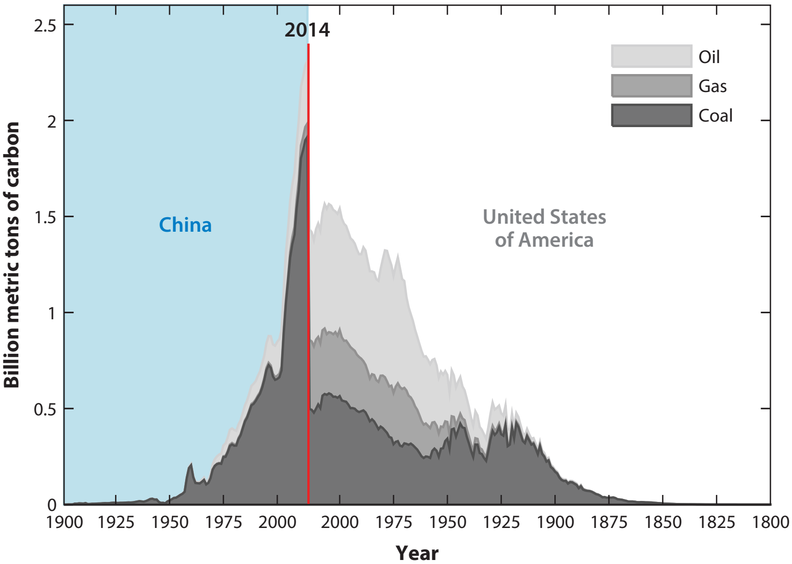

Figure 1

The mountain of carbon: carbon emissions by fuel type for the United States and China. From the origin to the middle of the graph, we see the emission trajectory of China. Starting at the right and going to the center, we see the emission trajectory of the United States. The area under the curve (the mass of the mountain) amounts to the total historical CO_2 emissions from fossil fuel combustion from the top two emitters.

errors are (*a*) inadequately reported quantity of fuel used and (*b*) the carbon content of said fuel used.[1] Guan et al. (2012) use national-level data on fuel use and provincial-level data on fuel use to separately calculate CO_2 emissions at the national level. They show that the difference between the two calculations is equivalent to one year's worth of Japan's emissions. Guan et al. (2012) point out that this difference may be due to updated coal use data at the national level and that data at the provincial level may not have been updated. However, emission figures from China have been questioned due to their politically sensitive nature in the international debate on climate regulation and mitigation efforts. Z.X. Zhang (2014) also provides an excellent discussion of these issues in association with energy pricing and subsidy systems in China.

2.2. Drivers of Carbon Emissions

When drivers of CO_2 emissions are modeled at an aggregate level, the most commonly invoked framework is the Kaya identity, which is based on Ehrlich & Holdren's IPAT (impact = population × affluence × technology) identity. The Kaya identity is more of a conceptual relationship rather than a specific equation governing the relationship between CO_2 emissions and their drivers. It is given by Equation 1:

$$CO_2 = \underbrace{\text{population}}_{p} \times \underbrace{\frac{\text{GDP}}{\text{population}}}_{g} \times \underbrace{\frac{\text{energy}}{\text{GDP}}}_{e} \times \underbrace{\frac{CO_2}{\text{energy}}}_{c}. \quad (1)$$

The identity hypothesizes four main drivers of CO_2 emissions: population (p), per capita affluence (g), energy intensity of GDP (e), and carbon intensity of the energy sector (c). The last two terms are often collapsed into a single term, which is the carbon intensity of the economy (CO_2/GDP) (e.g., Raupach et al. 2007).

Figure 2 uses the data provided by the World Development Indicators (World Bank 2013) to show the trajectory for these four drivers for the United States and China. Both countries' populations have grown relatively rapidly in comparison to those of other developed countries (e.g., Germany, France, Japan). Between 1971 and 2009, China's population grew by 490 million (1.2% p.a.), whereas the US population grew by 100 million (1.0% p.a.). The growth in China's real per capita GDP is well documented. Over this 40-year period, it grew at 7.8 p.a., resulting in a 17-fold increase. The US increase in per capita GDP over this time period was 1.79% p.a. and resulted in a doubling of per capita GDP. If one regards this progress in levels instead of in growth terms, China's per capita GDP increased by US$2,081 (2000 number), whereas the US per capita GDP increased by US$17,900 (2000 number). In summary, both countries became significantly more wealthy and populous over the past 40 years.

Figure 2*c* displays the energy intensity of GDP, which is calculated by dividing total energy consumption by GDP. The energy intensity of GDP in the United States fell by 1.96% over this period, as documented elsewhere (e.g., Auffhammer 2007). In comparison, China's energy intensity, according to the World Bank measure of energy consumption, fell at double that rate (by 4.03% per year).

Although the energy efficiency improvements in the Chinese economy have been widely studied and have been the target of repeated policy interventions at the central and provincial levels, they

[1]The mapping of fuel use to emissions may vary across time and space, as the efficiency of burning fossil fuels depends on the combustion technology. Improvements in, e.g., boiler heat rates represent one avenue for mitigation, which has to be empirically captured through adapting this mapping. Further sector-specific opportunities for future carbon sequestration may significantly alter these conversion factors.

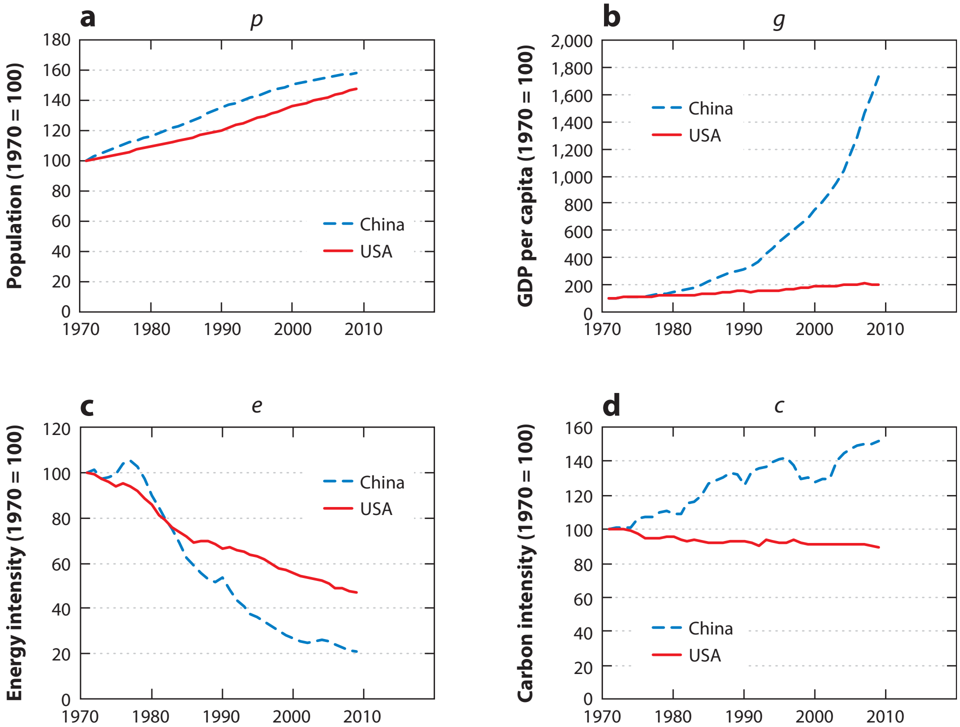

Figure 2

The Kaya identity drivers of CO_2 emissions: China and the United States. In each panel, the dashed blue line shows the trajectory for China and the solid red line the trajectory for the United States.

are not a sufficient mitigation mechanism. Increases in the carbon intensity of the energy consumed at the economy-wide level can offset or swamp the effects of energy efficiency improvements. **Figure 2*d*** indicates a most interesting divergence between the United States and China according to the World Bank data: The carbon intensity of US energy consumption has fallen at roughly 0.30% per year, much of which is possibly due to a shift from coal and oil toward less-carbon-intensive natural gas as an energy source. The opposite has happened in China: The carbon intensity of energy consumption has grown by 1.11% per year over the past 40 years. **Figure 2*d*** shows that there was a steady increase in this measure until the late 1990s, with a significant drop between 1996 and 2002. The years since 2002 have been marked by a sharp and steady increase in the carbon intensity of energy, equivalent to a 22% increase over the 1970 value in just 7 years.

3. ADDRESSING CLIMATE CHANGE IN CHINA: AN OVERVIEW OF INSTITUTIONS AND POLICIES

Driven by concerns about energy security and sustainable development and by mounting international pressure, China has accelerated its efforts to address climate change. The first signs of a national effort to address climate change emerged in the early 1990s. In 2007, China became the first country in the developing world to release a comprehensive national climate change plan (NDRC 2007). In 2009, during the UNFCCC COP15 in Copenhagen, the Chinese government made a commitment to reduce GHG emissions per unit of GDP by 40–45% relative to a baseline year of 2005 by 2020. The historical record shows that China has been able to significantly reduce the energy intensity of the economy, which is of course partially due to the rapid growth rate of its economy.

According to official statistics, during the eleventh Five-Year Plan (FYP)[2] period (2006–2010), the energy intensity of GDP was reduced by 19.1%, which came close to meeting the 20% reduction target set. By 2013, China had managed to cut its energy intensity of GDP by 28.5% relative to 2005 levels and to increase the share of nonfossil fuel in primary energy to 9.8% (NDRC 2014a). These steps were achieved through a portfolio of strict top-down policies. In what follows, we review the major institutional arrangements and key current and past policies passed by the Chinese government to address climate change.

3.1. Institutional Arrangements for Combating Climate Change

The institutional arrangements for addressing climate change at the national level have been continuously strengthened since the early 1990s. In 1990, the central government established a National Climate Change Coordination Team to facilitate both governmental engagement in international negotiations and domestic affairs related to climate change. The team, led by a state councilor, was under the supervision of the Environmental Protection Commission and set up an office in the National Meteorology Bureau. In 1998, the team was transformed into the National Climate Change Strategy Coordination Team, led by the head of the State Planning Commission. At that point, the team involved more than 10 ministries as institutional members. The State Planning Commission [now known as the National Development and Reform Commission (NDRC)] was responsible for coordination between these institutional members. The team set up physical offices in the State Planning Commission. The Commission retained its authority over the team for a decade.

In 2007, to strengthen the leadership for combating climate change, conserving energy, and reducing emissions, the State Council (China's cabinet) established the National Leading Group to Address Climate Change, Energy Conservation, and Pollutant Discharge Reduction. This leading group, headed by the prime minister, is responsible for both international negotiations and the development of national policies and action plans for climate change mitigation/adaptation, energy conservation, and pollution control. This leading group is also the main coordinating body for more than 20 institutional members, which include the NDRC and other additional ministries, state administrations, and national bureaus. Among these additional members are the ministries of foreign affairs, finance, and environmental protection; the National Bureau of Statistics; and the State Forest Administration. The day-to-day operation of the leading group is divided into two physical national leading group offices located in the NDRC: the Leading Group Office for Climate Change and the Leading Group Office for Energy Savings and Emission Reductions. The Climate Change Office, which evolved from the previous National Climate Change Strategy Coordination Team, is charged with dealing with climate change issues at the national level as well as the development of national climate policies and action plans.

The NDRC is the hub for issuing national policies related to climate change. On the one hand, the two leading group offices are set up within this very powerful state agency. On the other hand,

[2]Every 5 years, China's central government issues a new FYP that outlines the country's socioeconomic development goals for the next 5 years. FYPs are passed by the Standing Committee of the National People's Congress, the highest level of government that has the power to legislate. The first FYP was made for the period of 1953–1957.

the NDRC also plays a major role in coordinating among member institutions to develop and implement national policies and action plans.

In addition to the national polices, which are issued by the National Leading Group for Energy Savings and Emission Reductions, institutional members have the authority to develop their own sector-based policies and action plans to address climate change. For example, the State Forest Administration issued *The Forestry Action Plan to Address Climate Change* (SFA 2010), and the Ministry of Industry and Information Technology (MIIT) released *An Action Plan for Addressing Climate Change in the Industry Sector (2012–2020)* jointly with the NDRC, the Ministry of Finance, and the Ministry of Science and Technology (MIIT et al. 2012).

At the provincial level, since 2009, almost all provinces and municipalities have also established leading groups to address climate change. These leading groups, normally headed by the top provincial and municipality leaders, coordinate among different departments to take collective action to combat climate change within their own regions. These groups are responsible for implementing various climate change–related policies that are issued by the central government, particularly the National Leading Group for Energy Savings and Emission Reductions. These groups also develop and implement regional policies for addressing climate change, conserving energy, and controlling pollution. This complex arrangement has resulted in an intricate web of climate, environmental, and energy policies across China's provinces and sectors.

3.2. China's Major Policies for Combating Climate Change

Following the Rio Earth Summit of 1992, the Chinese government issued *China Agenda 21: A White Paper on China's Population, Environment and Development* (State Council 1994). This agenda laid out general guidelines for addressing climate change. In chapter 18, which is devoted to environmental protection, the document proposed energy development and tree planting as important means to control GHG emissions and proposed determining GHG emission targets for China in accordance with the UNFCCC. The document also recommended the following specific actions to control GHG emissions in China: (*a*) saving energy, reducing energy consumption, and advancing technology in the industrial sector; (*b*) improving energy efficiency; and (*c*) increasing forest cover through afforestation/reforestation for carbon sequestration.

However, climate change was barely mentioned in China's tenth FYP. The tenth FYP (2001–2005), in the section entitled "Saving and Protecting Resources for Sustainable Use," casually mentioned that China would take part in "global environment and development causes," would fulfill its commitment to the international community, and would take measures to mitigate global climate change. No specific targets or timetables were set.

China strengthened its efforts to address climate change after 2005 in two major ways. First, reductions in energy consumption and CO_2 emissions were included as national mid- and long-term economic and social development goals to be reached by the country's eleventh and twelfth FYPs. In the eleventh FYP (2006–2010), China set forth a binding goal of reducing energy consumption per unit of GDP in 2010 by 20% relative to 2005 levels. In the twelfth FYP (2011–2015), the binding goals were to reduce energy consumption per unit of GDP by 16% and to reduce CO_2 emissions per unit of GDP by 17% as well as to increase the share of nonfossil fuels in primary energy consumption to 11.4% for the period of 2011–2015. The central government further broke down these goals into subnational targets at the provincial and municipal levels and delegated these subnational targets to provincial and municipal governments to achieve.

Second, to incentivize local government leaders to take effective actions to achieve the subnational targets assigned to their regions, the central government tied assessment of local government leaders' political performance to achievements made in CO_2 emission reductions and energy conservation. In 2010, the central government also launched an inspection program to oversee local government leaders' performance regarding energy conservation in 18 key regions. In 2014, the State Council issued a national policy that specified detailed evaluation criteria and methods used to assess local government leaders' performance regarding CO_2 emissions reductions and energy conservation (NDRC 2014b).

During these eleventh and twelfth FYP periods, the Chinese government developed a series of climate change policies and action plans. **Table 1** lists five major national policies and action plans issued by the central government (by the State Council or NDRC) since 2005. All these policies and action plans commonly propose six major types of policy measures.

Promoting energy conservation and increasing energy efficiency are one key common measure taken by all the policies listed in **Table 1**. Strong legal and financial arrangements were made to support this measure. In Article 5 of the Energy Conservation Law of People's Republic of China, which was first promulgated in 1997 and amended in 2007 (NPC 2007), it is stipulated that including energy conservation in national or local medium- and long-term economic and social development plans is mandatory. Article 6 of the law stipulates a system for achieving energy conservation and an evaluation system, which assesses local leaders' achievements in energy conservation. The national government also used subsidies to implement specific programs for energy conservation, to support R&D, and to promote energy-saving technology adoption; it also reformed the pricing system for energy products (Z.X. Zhang 2014).

In 2012, the State Council released the *Twelfth Five-Year Plan for Energy Saving and Emission Reduction* (see State Council 2012), aiming to transform China's economic development mode, to establish an energy-saving and environmentally friendly society, and to strengthen the capacity of sustainable development. Because the industrial sector is responsible for the lion's share of energy consumption (accounting for 70% of energy consumption during the eleventh FYP period), the Chinese government made a strong effort to increase energy efficiency and promote energy conservation in the industrial sector. The two most significant national programs are the Energy Conservation Actions of the Top 1,000 Key Enterprises and Low-Carbon and Energy Conservation Actions of the Top 10,000 Enterprises, which were implemented during the eleventh and twelfth FYP periods, respectively (NDRC 2011b).

Adjusting the energy mix and developing low-carbon/clean energy are another key measure taken to reduce CO_2 emissions, given that coal production accounted for more than 70% of total

Table 1 Major national policies and action plans for climate change mitigation

Year	Policies and action plans	Issued by	Common measures
2007	China's National Climate Change Program	NDRC (2007)	1. Adjusting industrial structure 2. Promoting energy conservation and increasing energy efficiency 3. Adjusting the energy structure and developing low-carbon/clean energy 4. Increasing carbon sinks (mainly in the forest sector) 5. Controlling non-energy-related GHG emissions 6. Promoting low-carbon initiatives (low-carbon cities, local carbon transportation, low-carbon communities, etc.)
2008	China's Policies and Actions for Addressing Climate Change	State Council (2008)	
2011	China's Policies and Actions for Addressing Climate Change	State Council (2011a)	
2011	Working plan of GHG emission control for the twelfth FYP	State Council (2011b)	
2014	China's National Plan on Climate Change (2014–2020)	NDRC (2014a)	

primary energy production and coal consumption accounted for 68–69% of the total energy consumption in China during 2000–2010. The Renewable Energy Law of the People's Republic of China was passed in 2005 and was amended in 2009 (NPC 2009), aiming to promote renewable energy development, to increase and secure energy supply, and to adjust energy structure. The NDRC issued *The 11th FYP for Renewable Energy Development* (see NDRC 2008), seeking to increase the share of renewable energy consumption in total energy consumption to 10% in 2010. The NDRC also used subsidies to support the development of renewable energy and low-carbon energy. Significantly, the above energy-related measures were driven by the government to focus not only on climate change mitigation, but also on energy security and sustainable development.

4. INSTRUMENTS FOR GREENHOUSE EMISSION CONTROL IN CHINA

China has traditionally relied on standards and a pollution levy system to regulate pollution discharge throughout the country. Recently, the Chinese government also decided to use permit trading to mitigate climate change. Establishing a national carbon market, based on the experience gained from seven regional pilot carbon markets, is at the top of the national policy agenda for the thirteenth FYP period (2016–2020). A proposal to levy a carbon tax is also under discussion. In this section, we therefore review the key instruments used for pollution control currently adopted in China, which may help control not just criteria pollutants but also GHGs.

4.1. The Pollution Levy System

The pollution levy system has been the main economic instrument used by the Chinese government to control pollution since 1979. It covers a wide range of pollutants and polluters and has generated significant revenue that is used for pollution control. According to a speech given by Zou (2014), between 1979 and 2013, the total amount of pollution fees collected topped RMB 239 billion yuan (~US$37 billion). By 2014, the system had covered more than half a million fee-paying polluters. In essence, it is a fee system with significant downstream coverage, in which emission fees are charged at the point they are discharged, and is based on the polluter-pays principle.

The levy system was initially proposed by the National Leading Group for Environmental Protection at the end of 1978 and was piloted in 27 provinces during 1979–1981. With a document entitled "Tentative Means for Charging Pollutant Discharge Fees" issued by the State Council (State Council 1982), the levy system was formally established in 1982. The document specifies that a pollution fee shall be charged on those pollutants that are discharged in violation of national standards. The system regulates 21 pollutant types that fall into three major categories: (*a*) air pollutants, such as SO_2, H_2S, NO_x, and CO; (*b*) water pollutants, such as toxic materials (e.g., mercury, cadmium, arsenic) and wastewater constituents (e.g., COD, BOD, PH); and (*c*) solid waste. Rather than charging fees on all 21 pollutants as a true Pigouvian tax scheme would, Article 5 of the document specifies that "among waste water, air pollution and solid waste discharged, if more than two toxic materials (pollutants) are discharged from the same outlet, only the pollutant that is required to pay for the highest fee amount shall be charged."

The levy system was modified in 2003, when a new document entitled "Ordinances for Collection and Utilization of Pollution Fees" was issued as State Council Decree No. 369 (State Council 2003) to replace the previous "Tentative Means for Charging Pollutant Discharge Fees" (State Council 1982). Four kinds of major modifications were represented in the new document. First, more pollutants were included in the levy system. Most notably, the document included noise as a new category for pollution charge. For the previously existing three categories (i.e., wastewater discharge, air pollutants, and solid waste), the document expanded the coverage of pollutants. For example, for wastewater discharge, there were now 61 types of toxic materials and pollution constituents; for air pollutants, 44 pollutants were covered. Second, for water, solid, and air pollution, the government now charged the emission fee on the total amount of pollutant emitted, and not only on the amount that exceeded the national standard. Third, for water there was a two-tier fee structure, whereby the fee paid for the amount of emissions exceeding the national standard was higher than the fee charged for the portion of emissions below the standard. This structure was similar to the block rate pricing structure common in water and electricity pricing. Fourth, fees were charged for multiple pollutants rather than for a single pollutant. If more than two pollutants were discharged from the same outlet, the fee was charged on pollutants that were ranked in the first three places in terms of their pollutant equivalent (PE). The unit fees for wastewater discharge and air pollutants were RMB 0.7 yuan and RMB 0.6 yuan, respectively. However, these per unit fees set only the lower bound. Regions might be allowed to charge higher per unit fees, considering their local conditions for pollution control.

For solid waste disposal, a fee was charged according to the quantity of solid waste disposed, but differentiated unit prices were charged for different types of solid waste. For noise, a fee was charged only for noise released in excess of national standards.

Compared with the old levy system, which essentially charged only for a single pollutant, the revised levy system was somewhat improved but still left a significant portion of the pollutants untaxed. Moreover, charging RMB 0.7 yuan/PE of wastewater disposal and RMB 0.6 yuan/PE of air pollutants was considered far below the marginal external or abatement costs at or near the socially optimal level of emissions. As a result, most firms chose to pay the much lower pollution fee rather than abating the pollution (Wang et al. 2014).

The levy system was further revised in 2014 with a document jointly released by the NDRC, the Ministry of Finance, and the Ministry of Environmental Protection to adjust the fee schedule and to tighten up the treatment of heavy metals (NDRC et al. 2014). The new levy system was slated to be implemented at the end of June 2015. The document stipulates that the unit fee for wastewater discharge (particularly regarding COD, ammonia, lead, mercury, cadmium, chromium, and arsenic) shall be increased from 0.7 yuan/PE to 1.4 yuan/PE and that the unit fee for air pollutants (particularly SO_2 and NO_x) shall be increased from 0.6 yuan/PE to 1.2 yuan/PE. To address the increasing environmental hazards from heavy metal discharge to water bodies, the document specifically stipulates that "the pollution fee must be charged on the discharge of lead, mercury, cadmium, chromium and arsenic according to their PE, regardless whether they are among the first three major pollutants discharged." For other pollutants, the new system still charges for only the first three major pollutants.

Reviewing the evolution and design of the levy system, one can make the following major observations regarding its main design features. First, although the system covers more than 100 pollutants falling into five major categories, the pollution charge is imposed only on the first three major pollutants. Second, it has traditionally focused on regulating the discharge of SO_2, NO_x, COD, and ammonia and has only recently paid attention to heavy metals. Third, even though higher pollution rates will be in effect by the new system in 2015, they are believed to be below the marginal external or abatement cost at or near the socially optimal emission level and may thus not provide strong incentives for firms to abate pollution (Wang et al. 2014).[3]

[3]According to Wang et al. (2014), the new pollution charge rates to be applied in 2015 were actually calculated by taking the average abatement cost of pollutants listed in the levy system prevailing during 1982–2003 and by using prices prevailing in the 1990s. Therefore, the current abatement cost ought to be higher, given China's rapid economic development and increasing inflation rate in the past two decades.

Over time, a relatively solid legal system has been developed to support the levy system. One pivotal law supporting the levy system is the Environmental Protection Law of People's Republic of China, which was tentatively enacted in 1979 (NPC 1979), amended in 1989 (NPC 1989), and further revised in 2014 (NPC 2014). Article 18 of the 1979 law stipulates: "Pollutants discharged in excess of the prescribed national discharge standards shall be charged a fee, based on the quantity and concentration of discharged pollutants."[4] Article 43 of the 2014 law further emphasizes: "Enterprises, institutional organizations and other production entities shall pay a pollution fee according to relevant national stipulations. All collected pollution fees must be exclusively used for pollution control. Entities that are charged for environmental tax are not charged a pollution fee." Over time, five other laws were gradually enacted and are the legal cornerstones of the system. These five laws are Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution (Article 11 in the 1987 version and Article 14 in the 2000 revised version) (NPC 1987, 2000), Law of the People's Republic of China on the Prevention and Control of Water Pollution (Article 74 of the 2008 revised version) (NPC 2008), Marine Environment Protection Law of the People's Republic of China (Article 11 of the 1999 revised version) (NPC 1999), Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste (Article 56 of the 2004 version) (NPC 2004), and Law of the People's Republic of China on Prevention and Control of Pollution from Environmental Noise (Article 16) (NPC 1996). In addition to these six national laws, a series of regulations and acts have been issued by ministries and provincial governments. Local governments have also issued a number of regulations to support the system.

Local environmental agencies at the county level are the key players enforcing the levy system. The practical implementation of the system is as follows. At the beginning of each year, all polluters are liable for paying their pollution fee ex ante. Firms, small business owners, and government agencies submit their pollution discharge plans for the year by filling out a registration form released by the Ministry of Environmental Protection. They need to report the type, quantity, and concentration of pollutants that they anticipate discharging during the year. The local government agencies then register the information submitted and use data sent from automatic monitoring equipment for verification.[5] If cheating is detected or data are not reported, the government agencies decide on the types and quantity of pollution discharge for the firms. Hence the levy system heavily relies on individual polluters' self-reported information. Monitoring and verification are of key importance to the system. These features are of course problematic for CO_2 as a pollutant because its emissions are not really monitored for most sources.

Since 1979, the levy system has generated an important stream of revenues for environmental protection in China (Yang & Wang 1998). In 2013, annual pollution fee revenues were more than RMB 2 billion yuan (equivalent to more than US$0.3 billion) (MEP 2014), which is a fivefold increase in revenues collected compared with 1995. As specified in a series of documents issued by the national government,[6] the pollution fee collected by the local governments must be included as

[4]In the Environmental Protection Law amended in 1989, Article 18 states: "Enterprises and institutions discharging pollutants in excess of the prescribed national or local discharge standards shall pay a fee for excessive discharge according to state provisions and shall assume responsibility for eliminating and controlling the pollution."

[5]In principle, the polluters must install automatic monitoring equipment. For those polluters that have difficulty installing automatic monitoring equipment, other verification methods are also applied.

[6]These documents include "Tentative Means for Charging Pollutant Discharge Fees" issued by the State Council (1982), "Financial Management and Accounting Methods for Charging Fees for Pollutants Discharged in Excess of Standards" jointly issued by the Ministry of Finance and the Ministry of Construction in 1984 (MOF & MOC 1984), and "Ordinances for Collection and Utilization of Pollution Fees" issued by the State Council (2003).

local fiscal revenue and earmarked for environmental protection; 80% of the pollution fee collected must be directly used for pollution abatement

To reduce the possibility of misuse of the collected fees, the national government (in particular the Ministry of Environmental Protection and the Ministry of Finance) has also issued policies that require that the processes of fee collection and fee utilization be separate from each other. Despite the above efforts, lack of transparency of fee management and utilization is still a major concern. Moreover, as the amount of fees to be collected is based on polluters' self-reported information and verification is done by the local environmental agencies, at the local level major rent-seeking concerns may result in capture of the local regulator.

4.2. China's Pilot Carbon Markets

The potential establishment of a national carbon market has grown as a topic of interest since 2010. In the twelfth FYP, gradually establishing a carbon emission trading system is explicitly listed as one important means to control GHG emissions in China. Since 2010, the central government has moved in the direction of establishing a national carbon market and has made an ambitious plan to have a national carbon market in the early operational stages by 2016.

Responding to the call in the twelfth FYP for the establishment of a national carbon market and to build experience, in 2011 the NDRC issued a notice to pilot carbon emission trading in five municipalities (Beijing, Tianjin, Shanghai, Chongqing, and Shenzhen) and two provinces (Guangdong and Hubei) between 2013 and 2015 (NDRC 2011a). In 2010, these seven regions together had a total population of 256.4 million people (almost one-fifth of the country's total population) and a GDP of US$1.78 trillion (one-third of national total GDP); they emitted 1,533 Mt of CO_2 (almost 17% of national total CO_2 emissions), and their energy consumption accounted for one-fifth of national total energy consumption (Jotzo 2013, Zheng 2014). Among the seven regions, Hubei and Chongqing, which are located in inland China, are relatively less developed and have economies that still heavily rely on the industrial sector, whereas Beijing and Shenzhen have economies that are dominated by the service sector. The energy intensity levels also vary greatly across these regions, with Shenzhen having the lowest level (0.6 ton/US$1,000) and Chongqing having the highest level (1.4 ton/US$1,000) in 2010.

Within 2 years of the announcement made by NDRC, the seven markets were up and running. The first pilot carbon market started operating in Shenzhen on June 18, 2013, followed by pilot markets in Shanghai (November 26, 2013), Beijing (November 28, 2013), and Guangdong (December 26, 2013). By June 19, 2014, when Chongqing opened its market, all seven pilot carbon markets were fully operational.

This section summarizes key design features and the performance of these seven pilot carbon markets. We discuss major issues related to the seven markets and potential challenges in establishing a national market.

4.2.1. Main design features of the regional markets. The key elements of any cap-and-trade system are coverage and scope, cap setting, permit allocation, the MRV (monitoring, reporting, and verification) system, and the compliance mechanism. As one of the stated purposes of the regional pilot markets was experimentation, these regions were encouraged to explore different models. **Table 2** summarizes some key design features of these seven markets.

The seven pilot markets jointly cover more than 10 billion tCO_2e (tons of CO_2 equivalent) p.a. during 2013–2015. Despite their differences in design features, all seven regional pilot markets shared the following features, as discussed in the literature (e.g., Jiang et al. 2014, Jotzo & Löschel 2014, Munnings et al. 2014, Qi & Wang 2014, Qi et al. 2014, Wu et al. 2014, Zheng 2014):

Table 2 Main design features of pilot carbon markets

	Shenzhen	Shanghai	Beijing	Guangdong	Tianjin	Hubei	Chongqing
Emission reduction target (2011–2015)	21%	19%	18%	19.5%	19%	17%	17%
Types of GHGs covered	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	All six GHGs
Annual emissions capped ($MtCO_2e$)	30	160	50–60	388 in 2013 and 407 in 2014	112–160	324	125
Share of regional total emissions	40%	60%	50%	40–42%	45%	33%	Almost 40%
Threshold for inclusion	Firms with annual emissions >50,000 tCO_2e and public buildings with construction area >20,000 m^2	Annual emissions >20,000 tCO_2e for the industry sector and annual emissions >10,000 tCO_2e for nonindustry sectors	Annual emissions >10,000 tCO_2e	Annual emissions >20,000 tCO_2e (annual energy consumption >10,000 tSCE)	Annual emissions >20,000 tCO_2e	Annual total energy consumption >60,000 tSCE	Annual CO_2 emissions >20,000 tCO_2e
Number of entities covered	635 entities and 197 public buildings	191	490	202 in 2013 and 193 in 2014	114	138	242
Sectors covered	Industry and service (public transportation included)	Industry and service (aviation, railways, and ports included)	Industry and service	Industry	Industry	Industry	Industry
Permit allocation methods (2013–2015)	Free allocation and auction	Free allocation (auction possibly open after 2015)	Free allocation	Free allocation and auction (3–5%)	Free allocation	Free allocation and auction (2.4% from government reserves)	Free allocation

Sources: various documents issued by governments and trading centers from pilot regions (Beijing DRC et al. 2014; Beijing Municipal Government 2014; Beijing People's Congress 2013; Chongqing Municipal Government 2014; Chongqing DRC 2014a,b; Guangdong DRC 2013a,b, 2014; Guangdong Government 2012, 2014; Hubei DRC 2014; Hubei Government 2013, 2014; SCEX 2014a,b; SEEX 2014a–d; Shanghai DRC 2012a,b, 2013a,b; Shanghai Government 2012, 2013; Shenzhen Government 2014; Shenzhen People's Congress 2012; Tianjin Government 2013a,b; Jotzo 2013; Jiang et al. 2014; Munnings et al. 2014; Qi et al. 2014; X. Zhang 2014; Z.X. Zhang 2014; and Zheng 2014).

1. All the markets include the electricity sector and involve direct and indirect emissions. Indirect emissions are mainly emissions from the consumption of electricity and heat. Although including indirect emissions may encourage local carbon transformation on the demand side in a regulated energy market in China, it also raises the concerns for double counting of emissions related to power generation.
2. All the markets allow covered entities to use a certain number of verified offsets generated by Chinese Certified Emission Reductions (CCERs) for compliance, although the allowed proportion of offsets varies from 5% in Beijing and Shanghai to 10% in Hubei, Guangdong, and Shenzhen.
3. All the markets prohibit borrowing but allow banking.
4. Covered entities in all seven markets are at the firm or organization level rather than at the installation level, mainly because of the dearth of data collected at the installation level. This is different from the EU Emissions Trading System (EU ETS) market, in which the covered entities are at the installation level.

As shown in **Table 2**, the annual emissions capped accounted for 33–60% of total emissions in these provinces or municipalities. The annual emissions capped in each region were determined by considering CO_2 emission reduction targets specified by the national government for each region and other key factors, such as economic growth, industrial structure, the structure of energy consumption, and the potential for emission reductions in each region. In essence, much like China's national emission reduction target is framed as an intensity target, the emission caps for the pilot markets are largely intensity based, denoted in terms of CO_2 per unit of GDP. As Jotzo (2013) and Han et al. (2012) discuss, the intensity-based target may increase the uncertainty over the absolute amount of emissions arising from China's continuous economic growth, from rapid structural change, and from uncertainty over future GDP growth. Following this logic, the total emissions in the pilot regions also become less predictable than in a scenario with an absolute cap. Below we discuss some additional peculiarities of the individual pilot markets.

A different inclusion threshold was used to determine covered entities, with Shenzhen having the lowest level (30,000 tCO_2e p.a.) and Hubei having the highest level (annual energy consumption of 60,000 tSCE[7] p.a.). Altogether, the seven pilot markets covered more than 2,000 entities.

In terms of sectors covered, Hubei, Tianjin, Chongqing, and Guangdong covered only large emitters from the industrial sector, whereas Beijing, Shanghai, and Shenzhen, where the value added of service sectors has a relatively high share of local GDP, covered both the industrial sector and the service sector. In particular, in Beijing and Shenzhen, where the share of value added of the service sectors is more than 60% and relatively low thresholds for inclusion are used, the total number of entities covered in these two regions (635 entities in Shenzhen and 490 entities in Beijing) is relatively bigger than in other regions. Covering more entities may help to control CO_2 emissions in these two cities but also brings challenges in terms of administrative capacity. Regarding sources to be covered, Shanghai and Shenzhen covered both stationary and mobile sources from transportation (such as aviation, railway, ports, and public transportation), whereas the other five markets covered only stationary sources. The difference in covered sectors across these markets implies potentially different abatement strategies and technologies across sectors. Abatement strategies in the construction sector in Shenzhen, for example, will be quite different from those employed in the steel, power, cement, and chemical industries in Guangdong. This

[7]tSCE denotes tons of standard coal equivalent. In the Chinese setting, 1 tSCE is roughly equivalent to 2 tCO_2e.

heterogeneity in mitigation strategies provides a potentially fruitful and interesting avenue for future empirical research.

All the markets allocated most (or all) permits freely on the basis of historical emissions (known as grandfathering) and benchmarking. However, Guangdong, Hubei, and Shenzhen also auctioned a small portion of permits, which is similar to the models used in California's cap-and-trade system and the EU ETS phase III. In Hubei, auctions occurred only for permits reserved by the government. In Guangdong, the government mandated that all covered emitters obtain 3% of their annual allowable permits through auctions in 2013. However, this regulation was lifted in 2014. In 2014, in Guangdong, the proportion of auctioned permits was designed to be 5% for the power sector and 3% for other sectors such as steel, petrochemicals, and cement. Permits were allocated on a yearly basis in all other six markets, except for Shanghai, where permits were freely allocated in a lump sum fashion in 2013 for the period of 2013–2015.

As for market participation, individuals are still restricted from participating in Beijing, whereas markets in Shenzhen, Tianjin, Guangdong, and Hubei are open to individual participation. Institutional investors are allowed to participate in the Hubei and Shanghai markets, and foreign investors are also permitted to participate in the Shenzhen and Guangdong markets.

All pilot markets have started to develop their own MRV system. However, they have used different protocols for MRV, and the MRV systems are at different developmental stages in different regions. For example, Shanghai is at a relatively advanced level among all regional markets in terms of developing methodologies, as it has released guidelines for GHG accounting and reporting and has developed a series of accounting and reporting methodologies for nine sectors, such as heating and power, steel, chemical industry, and aviation. In contrast, Chongqing has only released guidelines for GHG accounting and reporting. In general, most regions still have a limited number of qualified or competent verification entities and individuals. Shenzhen has designated 18 verification entities, followed by Beijing (15), Chongqing (7), Shanghai and Guangdong (5 each), Tianjin (4), and Hubei (2).

So far, all pilot markets have established their own trading platforms and have set up registry systems. Five regions—Beijing, Tianjin, Guangdong, Shanghai, and Shenzhen—have used existing environmental exchanges as trading platforms. Most regions have set up specific rules for trading and market oversight. Nonetheless, transparency in information disclosure is still a big issue for most of these markets.

Most pilot carbon markets, except for Shenzhen, do not have strong legal support. In Shenzhen, the carbon market is supported by a legal document ("Provisions of Carbon Emission Management of the Shenzhen Special Economic Zone") passed by the Standing Committee of the Shenzhen Municipal People's Congress, the legislative body in Shenzhen Municipality. All six other markets are supported only by normative documents issued by provincial and municipal governments, such as decrees of provincial government (Chongqing, Hubei, and Guangdong), mayors' decrees (Shanghai), and orders issued by the general office of a municipal government (Tianjin). Because the orders issued by the general office of a municipal government are at the lowest level on the spectrum of normative documents, the Tianjin market has the weakest administrative foundation for enforcement. As the success of compliance markets critically hinges on strong legal support, the lack of legal support in most pilot markets in China raises big concerns with respect to effective enforcement.

Compliance in all markets is determined annually, which means that each year, all covered emitters must surrender their permits before a deadline spanning from the end of May (Tianjin and Hubei) to July (Beijing and Guangdong). Before the deadline, a third party must verify emissions of all covered emitters. On the deadline date, an entity's emissions in the past year must not be in excess of the annual allowable permits allocated to it. If a certain emitter has a higher level of emissions than its annual allowable permits, it is required to buy permits or CCERs from the carbon market. Otherwise, it has to pay penalties. All pilot markets except for Tianjin have specified financial penalties for noncompliance: The financial penalties range from RMB 50,000 to 150,000 yuan/tCO_2e or between three and five times the market average (or highest) prices for excess emissions.

If an entity has a surplus of permits, most regional markets allow the covered entities to carry the surplus forward for compliance in future years. However, in the Hubei market, the surplus permits expire on the last business day in June of each year.

4.2.2. Performance of permit markets. From June 18, 2013—the opening date of the first regional pilot market (Shenzhen)—to November 21, 2014, the total volume of carbon traded in all seven regional markets was 13.14 MtCO_2e. Total trading value was approximately RMB 489 million yuan (equivalent to approximately US$78 million).

Figure 3 shows the market share of each regional market as a percentage of total emissions traded and the value of transactions. Among all seven markets, the Hubei market has the highest share of trading volume (46.3% of 13.14 MtCO_2e). In contrast, Chongqing has the lowest market share of trading volume (1.1%, equivalent to 0.145 MtCO_2e). In fact, all 0.145 MtCO_2e of trading in the Chongqing market took place on its opening date (i.e., June 20, 2014), with an average price of RMB 30.74 yuan/tCO_2e (~US$5 per ton). Although Guangdong had the highest level of emissions capped, the market appears to be not very active, as the trading volume accounted for only 10.3% (approximately 135 MtCO_2) of the total trading volume of all regional markets. In terms of the trading value, Hubei also has the highest share of all regional markets (29.7% of RMB 489 million yuan), followed by Shenzhen (almost one-fourth of RMB 489 million yuan).

Generally, the market prices in all seven regional markets in 2014 were in the range of RMB 20–90 yuan (~$US3–15), although in 2013 the prices were quite volatile in the Shenzhen market. **Figure 4** shows the prices in each of the markets.[8] As shown in **Figure 4**, the market prices were relatively stable in the Beijing and Shanghai markets: The prices in Beijing were between RMB 40 and 80 yuan/tCO_2e, and those in Shanghai were between RMB 28 and 48 yuan/tCO_2e. The peak prices in these two markets occurred between June and July of 2014, the deadline for compliance. The prices in the Shanghai market dropped to a large degree after the compliance deadline but started to recover after October 2014. According to observations made by the Shanghai Environment and Energy Exchange, the recovery of market prices in the Shanghai market after October of 2014 may be attributable to Shanghai's new policy allowing institutional investors to participate in the market.

Prices in the Guangdong market display greater fluctuations than do prices in other markets. Guangdong prices reached a peak in July 2014 and have continued to drop since then, especially after August 2014. Similar to the case for the Beijing and Shanghai markets, the peak price in July 2014 was driven by firms' incentives for compliance, as July 15 was the deadline for firms to surrender their permits allocated in 2013. The decreasing price after August 2014 may be because of the increased annual allowable permits (408 MtCO_2e in 2014 compared with 388 MtCO_2e in 2013) issued in the Guangdong market.

Market prices in the Hubei market were quite stable but stayed at a relatively low price level, within a range of RMB 20–30 yuan/tCO_2e. This stability at a low price may be attributable to a range of possible factors, including the relatively large number of annual allowable permits allocated (amounting to 324 MtCO_2e); diversified participants, including individuals and enterprises; and the mark off of surplus permits at the end of the annual compliance period.

[8]We did not include Chongqing because its transactions took place on a single date (June 20, 2014).

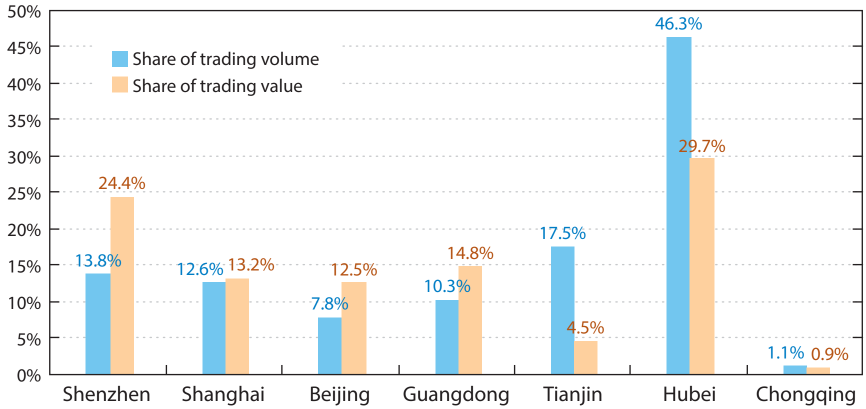

Figure 3

Share of market size of each individual market in all seven markets. Data from Shenzhen China Emission Exchange (2014).

4.2.3. Main issues with pilot markets. The seven regions have made impressive progress in establishing pilot carbon markets and experimenting with different models. These experiments will likely provide useful information feeding into the national government's deliberations over a national system. Nonetheless, the current fast-paced progress appears to be driven largely by strong political motivations and enthusiasm rather than by the implementation of carefully evaluated and well-crafted designs based on a process that takes significant time. Here are four issues we identify with regard to the currently existing pilot markets.

First, the lack of legal support and legal infrastructure is a fundamental obstacle to a carbon trading system taking effect. A cap-and-trade system in its essence is a compliance market critically relying on strong legal support for enforcement, including clearly defined property rights, rules for allocating permits, and specification of legal obligations. The lack of legal support in the current pilot markets in China not only reduces covered emitters' incentives to comply but also creates significant uncertainties in the market. Market-based instruments hinge on well-defined property rights. Without a clearly defined property right through the legal system, it is hard to imagine that a full-fledged market will be an effective operation.

Second, the lack of reliable emission inventory and monitoring data is a critical constraint to setting proper emission caps. Although setting the cap may be the most important policy decision, in China emission data are scarce. Without good data, the emission cap will likely not be set properly, which will eventually decrease the effectiveness of the trading system for reducing CO_2 emissions. Furthermore, the current tendency to set caps on the basis of achieving emission intensity targets instead of total CO_2 emission targets introduces year-to-year fluctuation based on GDP and obscures the overall goal of meaningful climate policy: the reduction of CO_2 emissions.

Third, lack of market infrastructure and administrative capacity is another key constraint. A well-functioning carbon market should be strongly supported by a well-developed MRV system, by good methodologies for accounting and measurement, and by a strong technical team to do verifications. These aspects are largely missing in most of the pilot markets.

Fourth, the lack of transparent information gives rise to significant uncertainty in the market. So far, most pilot markets lack information disclosure in terms of emission data of covered emitters, the methods used to determine total emissions to be capped and permit allocation, the types of firms participating in the markets, and the firms' detailed transactions.

Such a lack of information disclosure will inevitably dampen the incentives for potential market participants.

4.2.4. The path forward: regulating carbon at the national level. As the national government is determined to establish a national carbon market during 2016–2020, some initial preparations have been made. In 2013, the NDRC issued guidelines for firm-level GHG accounting and reporting for 10 industrial sectors, such as steel, petrochemistry, power generation, cement, glass, ceramics, and aviation (NDRC 2013). On December 10, 2014, the NDRC issued a document entitled "Tentative Means for Managing Carbon Emission Trading" as a concrete step toward establishing a national carbon market (NDRC 2014c). Despite these necessary steps taken to develop a national carbon market, further obstacles that are similar to the challenges faced by the regional markets discussed above will have to be overcome before such a market can go online.

First, China needs to develop a legal framework to support the enforcement of a carbon market. As the "Tentative Means for Managing Carbon Emission Trading" document issued by the NDRC (2014c) is only a sector-based, normative document, a national carbon market supported by this type of document raises concerns for the legal foundation of its future enforcement, given the jurisdictional complexities involved in enforcing China's large portfolio of environmental regulations. Second, China needs to invest in the necessary market infrastructure, such as trading platforms, registry systems, and an MRV system at the national level. Third, the lack of good emission data presents a big challenge in terms of setting a cap, deciding which sectors should be covered and how permits should be allocated to the covered entities, and designing accounting and verification rules. The above key components of a well-designed carbon market need to be built on reliable GHG emission (or energy consumption) data at the national, provincial, and/or firm (and even installation) level. Although experimentation through pilot carbon markets has enabled the government to collect emission data from more than 2,000 covered emitters (Zheng 2014), the existing data are far from sufficient, as China's current statistical system has barely covered GHG emission data, in particular data at the firm or installation level. Fourth, the coexistence of multiple policies targeted at carbon and energy emission reductions may dampen the price signal in a carbon market—similar to the experience of the EU ETS. Finally, the Chinese government may have to make a politically uncomfortable trade-off between efficiency and equity when making allocation plans across different regions.

5. CONCLUDING THOUGHTS

To effectively control GHG emissions, China may choose from a mix of climate policies ranging from a direct regulatory (command-and-control) system to market-based policies, such as permit trading or a carbon tax. China may continue using administrative and political measures to implement a direct regulatory system, but past experience has demonstrated that forcing a 19.1% energy intensity reduction during the eleventh FYP came at the costs of blackouts of industries and forcing a number of provinces to shut down large swaths of industrial capacity (Han et al. 2012). Minimizing the cost of achieving a given environmental goal is more likely to be achieved by a market-based approach with clearly defined property rights as a foundation. Therefore, it is worthwhile for the Chinese government to contemplate alternative policies such as a cap-and-trade system or a carbon tax.

Regarding the economic instrument to be used, the choice between a quantity-based carbon permit market and a price-based carbon tax has been at the heart of environmental economics literature. According to the seminal work of Weitzman (1974), in the absence of uncertainties, a carbon tax and a permit market should in theory achieve the same outcome in terms of emission

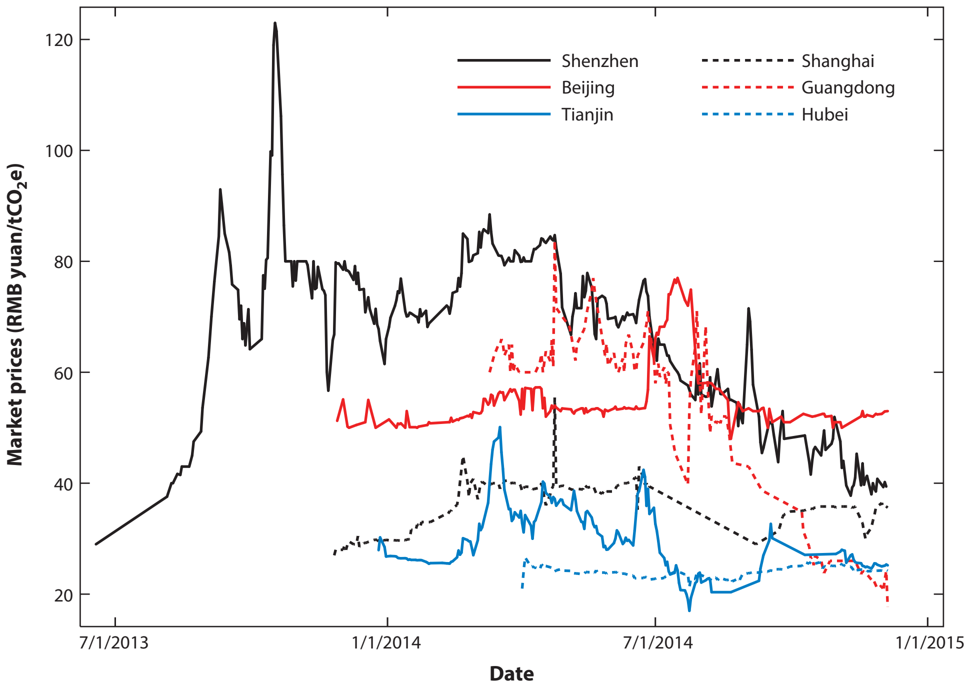

Figure 4

Price changes in regional markets. Data from Shenzhen China Emission Exchange (2014).

reductions, as both use carbon pricing to incentivize firms to reduce their emissions to a socially optimal level. However, if there exists uncertainty around marginal abatement costs, these two instruments can lead to very different levels of social welfare and total emissions in equilibrium. According to Weitzman, if the slope of the marginal benefit curve is flat, the price-based tax instrument may be preferred; if the slope of the marginal cost curve is relatively flat, the quantity-based instrument may be preferred.

In practice, although a carbon tax can help generate significant revenues for the government, it often faces strong political resistance. Which instrument should be used may also depend on the political, legal, and social context.

In China, establishment of a national carbon market has very strong political support, as the central government appears determined to use this system as an engine for more comprehensive economic reform of the energy sector and for technological advancement, in addition to the role of such a market in helping to reduce CO_2 emissions. A carbon market may also face much less resistance from firms. Nonetheless, China still faces a series of challenges for developing a national market from scratch. The costs of setting up such a market and the requirements for monitoring and enforcement are significant.

A simple carbon tax is an appealing and much simpler alternative that can draw on the existing significant policy infrastructure of the pollution fee system. First, China has more than 30 years of implementing a levy system, which is an admittedly imperfect Pigouvian system. In addition to developing a relatively solid legal foundation supporting this system, the government has also developed the necessary administrative capacities to implement this policy. Moreover, firms in China are also accustomed to paying pollution fees. So far, the system has accumulated some solid statistical information for firms liable to pay a fee: In 2013, the system covered 431,100 entities (MEP 2014). Therefore, instituting a carbon tax scheme in this levy system may result in much lower transaction costs compared with the case of quickly establishing a national carbon market.

The advantage of a carbon tax is that one can charge the carbon tax far upstream and thus avoid having to collect the tax directly from millions of sources. The key to success in regulating CO_2 emissions is to capture those large emitters. A carbon tax imposed on upstream firms using fossil fuels may capture a relatively high share of CO_2 emissions. Rather than proposing to completely shift from the levy system to a tax scheme, we think it may be more reasonable for China to consider the coexistence of a carbon tax scheme and a levy system. The levy system may still play its necessary roles in controlling criteria pollution and generating local revenues for environmental protection, whereas the carbon tax should be collected by the central government from fossil fuel producers. Meanwhile, the administrative capacities used in the levy system for fee collection and enforcement of the system may also be used for the tax system.

For the carbon tax system to work, the key will be getting the tax level right. In the proposed scenario, we do not claim to know what that number is. We simply suggest a simpler and more workable system than a carbon market to regulate carbon emission.

If the Chinese government is set on adopting a carbon market at the national level, we propose the potential advancement of a dual-control methodology that investigates not only the government setting of the cap, but also improving the measurement of accurate emission data. In the electrical engineering literature, the latter aspect is often referred to as M-measurement feedback control methodology. The relevant literature goes back to Prescott (1972), and a practical application is found in Rausser & Freebairn (1974).

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Contents

Errata

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