Review of Environmental Economics and Policy Advance Access published June 23, 2009

Symposium:
China's Environment

China's 11th Five-Year Plan and the Environment: Reducing SO_2 Emissions

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Introduction

China's rapid economic growth has been accompanied by a high level of environmental degradation. Pollution of the air, water, and soil poses significant threats to ecosystems and human health. While the severity of these threats has been known for some time, the pressure to maintain high rates of growth has generally taken precedence over environmental protection. Increasingly, however, it appears that these issues are being taken seriously by the top leadership of the Chinese government and are now being incorporated into policies and plans at the highest levels.

Among the pollutants known to cause significant health and ecosystem damages in China is sulfur dioxide (SO_2). Exposure to high concentrations of SO_2 can cause breathing problems, and long-term exposure can cause respiratory illness and aggravate existing heart disease. Sulfate particles, formed when SO_2 reacts with other chemicals in the air, can cause respiratory disease and premature death. Acid rain is quite severe in China, resulting in damage to forests, agricultural crops, fisheries, and structures. These effects are also felt by China's neighbors, particularly Japan and Korea.

Reducing SO_2 emissions has been the target of a number of recent efforts by China's environmental authorities. Although SO_2 concentrations have been reduced in many urban areas, total emissions remain unchecked. The 11th Five-Year Plan, covering the years 2006–2010, includes the target of reducing total SO_2 emissions by 10 percent from the 2005 level by 2010. As emissions are expected to grow significantly over this period without

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We are grateful to the editors and an anonymous referee for comments on an earlier draft. All views expressed in this article are those of the authors and do not reflect the opinions of the U.S. Environmental Protection Agency.

Review of Environmental Economics and Policy, 2009, pp. 1–20
doi:10.1093/reep/rep006

additional controls, attaining this target will require reductions from "business-as-usual" that are considerably higher. Two major policies are being implemented as part of the effort to reduce SO_2 emissions. The first is the shutdown across China of 50 GW of inefficient and highly polluting small power plant capacity. The second policy is the installation of flue gas desulfurization (FGD) equipment on new and existing coal-fired power plants.

This article, which is part of a three-article symposium on environmental policy in China,[1] analyzes the measures being taken to reduce SO_2 emissions as part of China's 11th Five-Year Plan. In the next section, we briefly review the current situation and trends in SO_2 emissions in China. Then we look at recent changes in China's planning process and how environmental objectives, including reducing SO_2 emissions, are increasingly being incorporated into government plans and policies. This is followed by a summary of a benefit–cost analysis of the two major SO_2-reduction policies designed to achieve objectives in the 11th Five-Year Plan. We participated in this analysis (JES 2007) as part of a team of researchers from the United States and China. Next we extend this analysis by developing more detailed estimates of the costs of the major policies, using data obtained during and after the U.S.–China study. We use these estimates in a dynamic computable general equilibrium (CGE) model of the Chinese economy to examine the economy-wide impacts of the SO_2 policies. The final section presents a summary and some conclusions.

SO_2 Emissions: Current Situation and Recent Trends

Despite a number of measures implemented by Chinese policy makers, total emissions of SO_2 have risen rapidly since the establishment of the People's Republic of China in 1949 and accelerated following the initiation of the country's economic reform in 1978. Figure 1 shows reported SO_2 emissions for the years 1950–2006. Definitional changes and statistical anomalies account for some of the more extreme fluctuations, but the overall upward trend is clear. Moreover, independent estimates of SO_2 emissions are consistently higher than the official figures from the State Environmental Protection Administration (SEPA) (see, e.g., Streets and Waldhoff 2000; Streets et al. 2000; Ohara et al. 2007).

Role of Coal

Coal dominates China's overall energy mix. The International Energy Agency (IEA 2007) estimates that in 2005, total primary energy use was composed of 72 percent coal and 22 percent oil, with natural gas, hydro, and nuclear power making up the remaining 3 percent, 2 percent, and 1 percent of demand, respectively.[2] Even the most optimistic policy scenario from the IEA (2007) projects coal comprising more than 60 percent of total demand in 2030.

Coal plays an even greater role in electricity generation. In 2005, about 79 percent of China's electricity was produced in coal-fired plants (IEA 2007, p. 597). Despite a substantial investment in new hydro capacity, only about 16 percent of total generation in 2005 came from hydro power. Oil and nuclear each made up about 2 percent of the total, with natural

[1]The article by Cao, Ho, and Jorgenson (2009) examines the costs and benefits of using "green taxes" to control air pollution in China. Vennemo et al. (2009) look at air and water pollution trends.
[2]Although not cited here, the IEA also estimates energy generated from biomass in China.

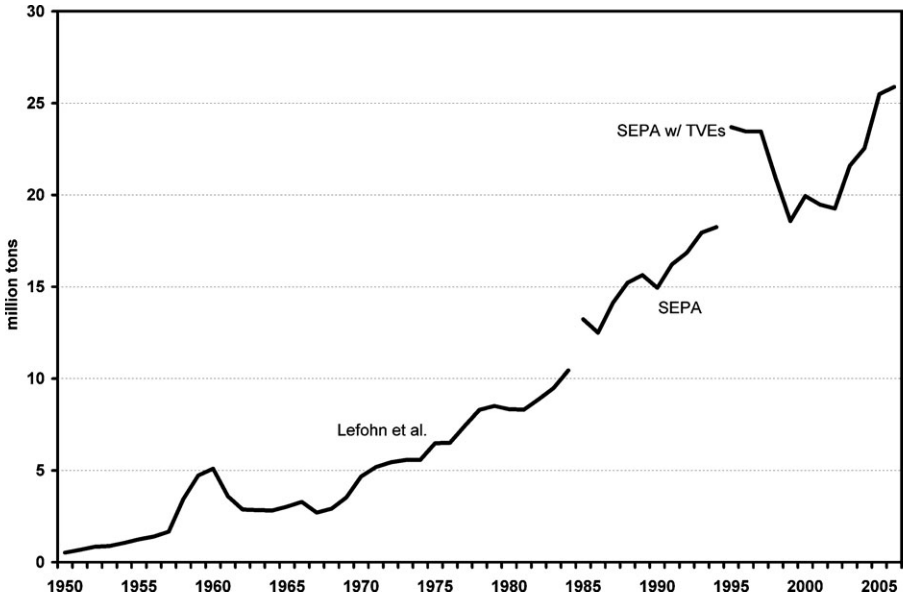

Figure 1 Reported SO_2 emissions, 1950–2006.
Source: Lefohn et al. (1999) and *China Statistical Yearbook* (various years).
Notes: Figures to 1984 are from an estimate by Lefohn et al. (1999). SEPA included township and village (TVE) industry in their official estimates starting in 1995, which accounts for the jump in that year. Some of the decline after 1997 may be due to under-reporting of coal use.

gas accounting for the remaining 1 percent. In order to keep up with rapid economic growth and alleviate shortages, the amount of coal consumed for power generation almost doubled between 2001 and 2006 (CSY 2007; CESY 2006). According to the World Bank (2007, p. 25), much of the new coal-fired electricity generation capacity installed during this period was in relatively inefficient medium-sized plants. In 2006, electricity generation accounted for about 50 percent of total coal consumption (CSY 2007).

Emissions of SO_2 in China are driven primarily by heavy coal use, coupled with limited abatement. In 2006, industrial sources (mining, manufacturing, and utilities) were responsible for 86 percent of reported SO_2 emissions, with electricity generation accounting for 47 percent (CSY 2007). Small power plants account for a disproportionately large share of emissions from the power sector. Iron and steel production, cement, and chemicals were the largest industrial sources after power generation. Transportation is currently a small but growing source of SO_2 emissions. For some time, emissions from household sources have been declining as gas and electricity have become more widespread in urban areas. In 1985, household use accounted for almost 20 percent of total SO_2 emissions, and household use of coal as briquettes and in other crude forms was a significant cause of urban air pollution. By 2005, household use had dropped to about 4 percent of total coal consumption.

Trends in Urban Air Quality

While total SO_2 emissions have continued to rise, trends in urban air quality appear to be more positive. Figure 2 shows the reported annual average concentration of SO_2 for major Chinese cities. Although averages of over 100 micrograms per cubic meter ($\mu g/m^3$) were common

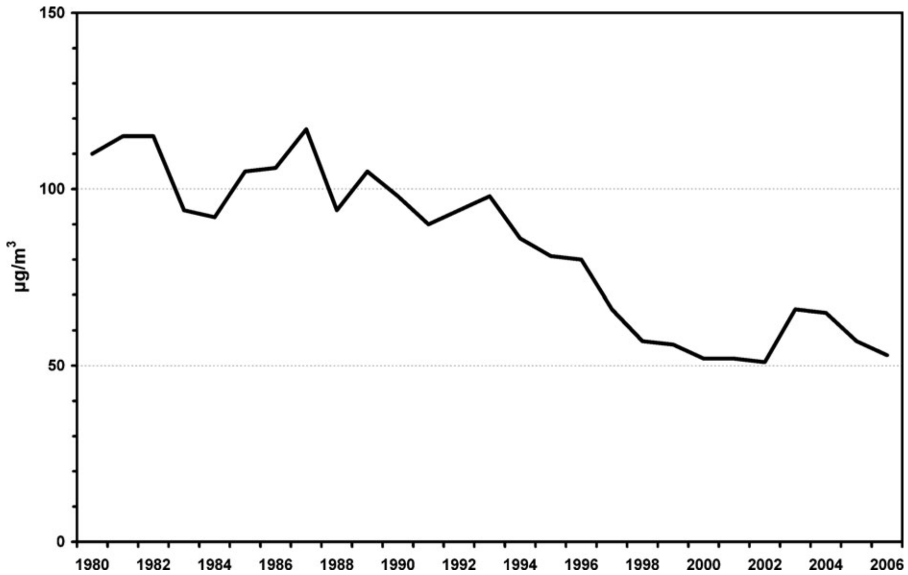

Figure 2 SO_2 concentrations in Chinese cities (annual averages), 1980–2006.
Source: Sinton et al. (2004) and SOE (various years).
Notes: The averages are simple unweighted means. In 2006, this dataset included 113 key cites for environmental protection (*huanjing baohu zhongdian chengshi*). Years before 2003 included fewer cities.

in the 1980s, only twice in the current decade—in 2003 and 2004—has the average exceeded 60 $\mu g/m^3$, China's Grade II standard for SO_2. In 2006, 87 percent of 559 monitored cities met or exceeded the Grade II standard (SOE 2006).[3] The shift of emissions from ground level sources to the high stacks of power plants is likely responsible for much of the improvement in air quality in urban areas, but it has also increased the long-range transport of pollutants.

Trends in Acid Rain

Although there has been progress in reducing SO_2 concentrations in many Chinese cities, acid rain continues to be a serious problem in some parts of China, particularly in the south. Acid deposition—both wet and dry—is caused by emissions of SO_2 and nitrogen oxides (NO_x).[4] Acid rain has resulted in damage to forests, crops, fisheries, and buildings. According to some estimates, one-third of the land area in China is affected by acid rain. The World Bank (1997) estimated the damage from acid rain in the early 1990s at about 0.7 percent of GDP. A more recent estimate by SEPA put damages at 110 billion *yuan* in 2003, or about 0.8 percent of GDP (Fu 2005). However, limited monitoring hampers the ability to determine the full extent of the effects of acid rain (Larssen et al. 2006).

The 11th Five-Year Plan and Chinese Environmental Policy

In the competition between economic growth and environmental protection, growth has generally come out ahead in China. However, environmental concerns are increasingly

[3]This is a larger dataset not available for previous years.
[4]NO_x emissions have risen as the number of vehicles in China has increased.

being incorporated into China's planning process at both the national and local levels. More recently, this has included targets for pollution control. The National Economic and Social Development 11th Five-Year Plan, ratified by the Fourth Plenary Session of the Tenth National People's Congress in March 2006, can be seen as an attempt to maintain rapid growth while incorporating increased concern for environmental sustainability and the widening income inequality that has also accompanied China's rapid growth.

The 11th Five-Year Plan, covering the years 2006–2010, grew out of a broad consultative process that included some of the most highly regarded economists in China (Naughton 2005). The plan assumes that China's economy is now market driven, and targets are now specified as either "expected" or "compulsory."[5] Expected targets are those that are anticipated to be achieved through the workings of market forces, with the government providing overall macroeconomic stability and the necessary regulatory institutions. Compulsory targets are those that are imposed by the central government, with enforcement the responsibility of central government agencies and local governments (Fan 2006; You 2007).

Major Targets of the 11th Five-Year Plan

Table 1 presents the major indicators and targets contained in the 11th Five-Year Plan, which include economic growth and structural change; resource issues such as population, energy, and pollution; and a number of indicators for well-being. Of the twenty-two indicators, fourteen have targets that are expected and only eight have targets that are compulsory. Of the compulsory targets, half are directly related to energy and the environment. The energy efficiency target—a 20 percent reduction in energy intensity over the five-year plan—is especially ambitious, reflecting a number of growing concerns of the central government. Among these concerns is energy security, as China has been forced to import increasing amounts of oil and natural gas and more recently has also been a net importer of coal (Oster and Davis 2008).

Five-Year Plans for Environmental Protection

In addition to the national five-year plan, other central government entities and provincial and local governments prepare more detailed five-year plans. The central five-year plan's target—a 10 percent reduction in major pollutants by the end of the five-year period—is disaggregated further in the National 11th Five-Year Plan for Environmental Protection (2006–2010), prepared by SEPA (see Table 2). This plan contains only five targets: three for water quality and two for air, including a 10 percent reduction in SO_2 emissions.

Perhaps one reason for the limited number of targets in the current Environmental Protection Plan was the poor performance under the 10th Environmental Protection Plan, which covered the years 2001–2005 and achieved only half of its fourteen major targets (see Appendix Table A1). In particular, the overall SO_2 target, which was set at 10 percent below the 2000 level of emissions, was exceeded by more than 40 percent.

[5]Even the Chinese terminology for the plan has changed. Although both *guihua* and *jihua* can be translated as "plan" in English, *guihua*, the Chinese term now used, connotes a more flexible guidance document than the more rigid *jihua* used for previous Five-Year Plans.

Table 1 Major social and economic indicators in the 11th Five-Year Plan

Indicators	2005	2010	Percentage change	Type
I. Economic growth				
GDP (tril. *yuan*)	18.2	26.1	7.5%	Expected
Per capita GDP (*yuan*)	13,985	19,270	6.6%	Expected
II. Economic structure				
Service sector share of value added (%)	40.3	43.3	[3]	Expected
Service sector share of employment (%)	31.3	35.3	[4]	Expected
Investment in R & D as a percentage of GDP (%)	1.3	2.0	[0.7]	Expected
Urbanization level (% of population)	43	47	[4]	Expected
III. Population, resources, and environment				
Population (mil.)	1,308	1,360	<0.8%	Compulsory
Energy consumption per unit of GDP			[−20%]	Compulsory
Water consumption per unit of industrial value added			[−30%]	Compulsory
Coefficient of irrigation efficiency	0.45	0.50	[0.05]	Expected
Rate of utilization of industrial solid waste	55.8	60.0	[4.2]	Expected
Farm land (mil. hectares)	1.22	1.20	−0.3	Compulsory
Decrease of major pollutants			[−10%]	Compulsory
Forest cover (%)	18.2	20.0	[1.8]	Compulsory
IV. Public service and people's wellbeing				
Average education (years)	8.5	9	[0.5]	Expected
Urban population covered by pension system (mil.)	174	223	[49]	Compulsory
Coverage of rural cooperative healthcare system (%)	23.5	>80	>[56.5]	Compulsory
Increase in urban employment (mil.)			[45]	Expected
Rural–urban migration (mil.)			[45]	Expected
Urban unemployment rate (%)	4.2	5	[0.8]	Expected
Per capita income in cities (*yuan*)	10,493	13,390	5	Expected
Per capita income in countryside (*yuan*)	3,255	4,150	5	Expected

Note: [] indicates change over the Five-Year Plan period.
Source: National People's Congress (2006) and Zhang (2006).

Table 2 Major targets in 11th Five-Year Plan for environmental protection

	Indicator	2005 Actual	2010 Target	% Change to achieve target
1	COD (mil. tons)	14.14	12.7	−10%
2	SO_2 (mil. tons)	25.49	22.95	−10%
3	Percentage of river sections under national monitoring program failing to meet Grade V National Surface Water Quality Standard (%)	26.1	22	−4.1 percentage points
4	Percentage of sections of 7 major rivers under national monitoring program meeting Grade III National Surface Water Quality Standard (%)	41	43	2 percentage points
5	Number of days in which urban air quality of key cities is superior to Grade II National Air Quality Standard exceeding 292 days (%)	69.4	75	5.6 percentage points

Source: SEPA (2007).

Government Efforts to Increase Compliance with Targets

In order to improve performance in the current planning period, China's leadership has implemented a number of measures intended to increase compliance. For example, the Central Committee of the Communist Party issued new rules on the promotion of local communist party officers and local officials (Central Committee 2006). These new rules emphasize that environmental protection is to be an important criterion for promotion. New projects are to be examined to see if they meet environmental standards and terminated if they do not (NDRC et al. 2006). In March 2008, SEPA was elevated to full ministry status, becoming the Ministry of Environmental Protection (MEP). It has been argued that this will give it equal status with other ministries and strengthen its position for ensuring compliance with environmental regulations and laws.

In addition to complying with general environmental laws and regulations, electric power plants are required to meet SO_2 emissions performance standards. Originally introduced in 1973, the performance standards were revised in 1991, 1996, and 2003. One problem with these standards is that they have been applied by vintage, older plants not currently required to meet the most stringent specifications.

Beginning with the 9th Five-Year Plan, covering 1995–2000, the government began to set limits on total SO_2 emissions, rather than just setting emissions rates. The "Two Control Zones" policy set limits on total emissions for "Acid Rain Control Zones" and "SO_2 Control Zones." The former comprise areas in southern China where acid rain has been severe, while the latter include cities in northern China with high ambient concentrations of SO_2. The "Total Emissions Control" policy set a nationwide limit on the emissions of twelve major pollutants, including SO_2 (Ellerman 2002).

In January 2008, SEPA and the National Development and Reform Commission (NDRC) issued the National Acid Rain and SO_2 Pollution Control 11th Five-Year Plan (SEPA and NDRC 2007). This plan specifies emissions targets for 2010 for each province overall as well as for each province's power sector. Targets range from a reduction of 25.9 percent from the 2005 level for Shanghai, to simply maintaining 2005 levels in Hainan, Tibet, Gansu, Qinghai, and Xinjiang. The plan also includes schedules for the installation of FGD equipment at specific coal-fired plants. Further, the plan includes a list of plants outside the power sector—mostly chemicals and ferrous and nonferrous metals—that are required to reduce SO_2 emissions. Finally, the plan includes a list of 679 small power plants targeted for closure. If completed, the shutdown of these small power plants would remove more than 50 GW of low-efficiency, highly polluting electricity generation capacity.

China also has some experience with market-based mechanisms for pollution control. The use of pollution levies in China goes back to the early 1980s. Emissions charges have been levied on more than fifty individual pollutants, including twenty-two air pollutants, of which SO_2 is the most important (Wang and Wheeler 2005). The levy originally applied only to emissions above a maximum allowable level, but in 2003 it was changed so that it applies to all discharges (Goulder 2005). In 2004, the levy for SO_2 emissions from electric power plants was raised from 200 RMB per ton to 630 RMB per ton, and in 2007, it was doubled to 1,260 RMB per ton (JES 2007). In 2004, China introduced a price premium for electricity generated by coal-fired power plants operating with FGD equipment. The 0.015 RMB per kWh premium is meant to subsidize the additional fuel costs for operating the FGD equipment. Fines are applied if the FGD equipment is in operation less than 90 percent of the time (JES 2007). While it is too early to assess the effects of the most recent increases in SO_2 levy rates, historically, low rates and design issues have limited the effectiveness of the levy system in reducing SO_2 emissions (Blackman and Harrington 2000; Ohshita and Ortolano 2006).

The U.S.–China Joint Economic Study

In September 2006, the United States and China began the U.S.–China Strategic Economic Dialogue (SED), a forum created for discussion of a range of issues of mutual concern at the highest official levels. It was agreed that the SED would convene semiannually, alternating between meeting in the United States and China. Treasury Secretary Henry Paulson, who had made numerous trips to China as Chairman and CEO of Goldman Sachs, was designated as the leader of the U.S. delegation. Vice Premier Wu Yi, who had helped to negotiate China's entry into the World Trade Organization (WTO), was designated as the leader of China's delegation. While discussion of China's exchange rate regime has been a high priority in the SED, investment, trade, intellectual property rights, energy, and the environment have also figured prominently in SED discussions.

At the first official SED meeting in Beijing in December 2006, it was agreed that the U.S. Environmental Protection Agency (EPA) and China's State Environmental Protection Administration (SEPA) would lead a joint study on energy efficiency and air pollution abatement in the United States and China. For the China portion of the study, the joint study team performed a benefit–cost analysis of the 11th Five-Year Plan goals for energy efficiency and SO_2 abatement.[6]

The preliminary summary of the U.S.–China Joint Economic Study (JES 2007) was completed and presented at the third meeting of the SED in Beijing in December 2007.[7] We focus here on the study's estimates of the benefits and costs of the two policies specified by SEPA and the NDRC to achieve the SO_2 reduction target in the 11th Five-Year Plan: the shutdown of 50 GW of small-scale power generation units and the installation of 167 GW of new FGD equipment on existing power generation units.[8] The expected net reduction in SO_2 emissions from the small power plant shutdown policy is 2.1 million tons. The installation of the FGD equipment is expected to result in a reduction of 5.4 million tons of SO_2 emissions. Base year (2005) emissions levels, 2010 business-as-usual (BAU) emissions projections, and the 2010 Five-Year Plan targets are shown in Table 3.

[6]The U.S. analysis relied primarily on the Regulatory Impact Analysis (RIA) done for the Clean Air Interstate Rule (CAIR), issued by the EPA in 2005. CAIR requires that the twenty-eight Eastern states and the District of Columbia reduce emissions of SO_2 and NO_x by 73 percent and 61 percent, respectively, below 2003 levels. These emissions reductions will also help urban areas attain ambient air quality standards for PM2.5 and ozone.

[7]The full name of the study is the U.S.–China Joint Economic Study: Economic Analyses of Energy Saving and Pollution Abatement Policies for the Electric Power Sectors of China and the United States. (The JES Summary for Policymakers is available at: http://www.epa.gov/airmarkets/international/china/JES_Summary.pdf.)

[8]All new power plants are required to install FGD equipment.

Table 3 SO_2 emissions targets for 11th Five-Year Plan

	2005	2010 BAU baseline		2010 Target		
	mil. tons	mil. tons	Change from 2005	mil. tons	Change from 2005	Change from BAU
Power sector	13.3	18	+35%	10	−25%	−44%
All other sectors	12.2	13	+6%	13	+6%	0%
Total	**25.5**	**31**	**+19%**	**23**	**−10%**	**−26%**

Source: JES (2007).

Policies in other sectors are projected to hold SO_2 emissions at only slightly above their base year levels (2005). Thus the overwhelming majority of emissions reductions required to achieve the Five-Year Plan's target of reducing total SO_2 emissions by 10 percent are expected to come from the power sector. The projected reductions required by the power sector are about 25 percent from the 2005 level and 44 percent from the BAU projection.

Due to the lack of a suitable existing model and the tight deadline for producing the preliminary study, the costs of the FGD policy were estimated using a spreadsheet model. The annualized cost estimate, including installation, operating, and maintenance costs for the FGD equipment, was 7.15 billion *yuan*. The net costs of the small-boiler shutdown policy were assumed to be zero (or possibly negative) and not included in the total costs used in the benefit–cost ratio calculation.[9]

The air quality improvements resulting from the two SO_2 reduction policies were estimated using the Community Multiscale Air Quality (CMAQ) model, which has been applied to China in previous collaborations between the EPA and Tsinghua University in Beijing. In addition to the reductions in SO_2, it was estimated that the policies would result in about a 5 percent reduction in the average concentration of PM2.5. The health and non-health benefits, including reduced damages to crops, buildings, and infrastructure, were calculated using the Environmental Benefits Mapping and Analysis Program (BenMap) model. The annualized benefits were estimated to be 35.4 billion *yuan*.

The preliminary study estimates of 35.4 billion *yuan* in benefits and 7.15 billion *yuan* in costs results in a benefit–cost ratio of approximately 5 to 1. However, due to a number of factors, the preliminary study most likely underestimated this ratio. First, the values used for morbidity and mortality were conservative. Second, not all of the damages to ecosystems and crops were quantified. Third, while the costs of the installation of the FGD equipment were included in the study period (2006–2010), additional benefits will accrue for many years thereafter. Unfortunately, full details of the calculations have not yet been made available to those outside of the Chinese government.

At the time of this writing, the full and final JES study was not yet complete. However, the preliminary study was considered to be a success by both governments, and there will be a follow-up study that will examine the feasibility of a national cap-and-trade system for SO_2 in China. An initial estimate performed as part of the JES using the spreadsheet model found that a cap-and-trade system could achieve the 11th Five-Year Plan reductions with a

[9]The JES also included an initial estimate of the economy-wide costs of the policies using a computable general equilibrium (CGE) model. We discuss our extended economy-wide analysis later in this article.

16 percent lower total cost. This estimate considered only a single trading option and did not include other measures, such as coal washing, fuel switching, and other technologies. Thus there is reason to believe that the cost savings from a cap-and-trade system could be considerably higher.

Extended Analysis of the 11th Five-Year Plan Abatement Policies for the Power Sector

In the previous section we briefly described the results of the JES study's (2007) analysis of the benefits and costs of the policies being implemented to achieve the SO_2 abatement target in the 11th Five-Year Plan. In this section we provide a more detailed analysis of these policies using data from the JES and additional information obtained after the preliminary study was completed.

Small-Unit Shutdown Policy

At the end of 2005, almost one-third of China's thermal power generation capacity was provided by small-scale power generation units, where small scale is defined as a unit with capacity of less than 100 MW.[10] Most of these small-scale units are coal-fired, but some are oil and diesel units serving localities that had in the past experienced severe electricity shortages. These small units are generally inefficient in their use of energy and also highly polluting. The average total cost per kilowatt hour for small plants is almost three times the cost for large plants. This is due mostly to smaller plants' higher fuel requirements per kilowatt hour of electricity, with diesel-fired plants being particularly inefficient (see Appendix Table A2). As noted above, as part of the 11th Five-Year Plan's emphasis on energy efficiency and pollution control, 50 GW of small-scale power plant capacity has been targeted for closure by the end of the plan period (2010).

Implementing this shutdown policy requires that replacement capacity be built. However, since this policy is being implemented gradually over five years, the individual units shut down are proportionately small and widely spread geographically, and electricity supplied to the grid is fungible, the actual cost of this replacement capacity can be assumed to be an average for all new capacity installed over the plan period. Thus the direct cost of the shutdown policy would be equal to the cost of producing the replacement electricity, less the operating and maintenance costs that would have been incurred by operating the small units plus decommissioning costs.[11]

The decommissioning costs could include the shutdown of the small plants themselves and perhaps the retraining and relocating of displaced workers. The value of any scrap materials and the land the plant was located on should be accounted for as negative costs. Although estimation of the total direct costs of the shutdown of these very heterogeneous units is difficult, a limited analysis by the Energy Research Institute indicates that when high fuel

[10]The NDRC's Energy Research Institute estimates that in 2006 there was about 115 GW of capacity provided by coal- and oil-fired units under 100 MW, out of a total of 391 GW of thermal-fired capacity.
[11]The location of the replacement plants may also mean higher transmission costs.

costs and the value of freed-up land are fully accounted for, total direct costs of the shutdown policy are negative—even without taking into account the environmental benefits.[12]

As discussed in the previous section, the environmental benefits of the small-unit shutdown policy are substantial. The JES (2007) estimated that the shutdown of 50 GW of small units would save almost 30 million tons of coal over the 11th Five-Year Plan period and that the annual reduction in SO_2 emissions from the policy would be about 2.1 million tons.

FGD Installation Policy

At the end of 2005, FGD equipment had been installed on 46.2 GW of coal-fired electricity generation capacity—12 percent of the total. In order to meet the SO_2 reduction target of the 11th Five-Year Plan, an additional 167 GW of FGD equipment is scheduled to be installed on existing power generation units by 2010.[13] Moreover, all new power generation units constructed during the 11th Five-Year Plan—estimated in the JES (2007) at 250 GW of capacity—are mandated to have FGD equipment. Thus, if the FGD policy is fully implemented, there will be a total of 463.2 GW of FGD equipment installed on coal-fired power plants by the end of 2010. The IEA's reference scenario (IEA 2007) projects total coal-fired electricity generation capacity at 547 GW in 2010. This means that FGD would be installed on almost 85 percent of total coal-fired capacity.

The costs of the FGD installation policy can be divided into two types: direct and economy-wide. We discuss the direct costs here.[14] The direct costs of the FGD policy include the capital costs of the FGD equipment and operation and maintenance costs, which include additional electricity for the operation of the equipment and thus an increase in fuel inputs.

Capital costs for FGD units manufactured in China have fallen by more than half since the 1990s as domestic firms have learned to produce the new technology. These costs now range from 150 *yuan*/kW for a 600 MW plant to 180 *yuan*/kW for a 100 MW plant. As the cost of constructing a 600 MW plant without FGD is approximately 4,000 *yuan*/kW, the addition of FGD equipment represents about a 3.8 percent increase in capital costs. The unit operating cost of the FGD equipment (per ton of SO_2 removed) depends on the size of the plant and sulfur content of the coal used, and ranges from 1,244 *yuan*/ton of SO_2 for a 100 MW plant to 800 *yuan*/ton for a 1,000 MW plant (for coal with a sulfur content of 1 percent). Low-sulfur coal raises the cost per ton removed, from 1,020 *yuan*/ton for 1 percent sulfur coal to 1,840 *yuan*/ton for 0.5 percent sulfur coal. The Chinese Academy for Environmental Planning (CAEP 2007) reports that coal with a sulfur content of less than 0.5 percent makes up 30 percent of coal combusted in the power sector, with coal having a sulfur content of 0.5–1 percent making up another 35 percent. Averaging over plant sizes and coal types, CAEP estimates that running FGD equipment raises operating costs by 2.4 percent. In terms of the price of delivered electricity, which includes transmission costs, the additional cost of running FGD equipment is only 1.5 percent.

Just as with the small-unit shutdown policy, if there is full compliance with the FGD policy, the environmental benefits are expected to be substantial. SO_2 emissions from the power

[12]Personal communication with the authors.

[13]This 167 GW of FGD includes 39 GW carried over from the previous Five-Year Plan and 128 GW of installation newly mandated.

[14]The economy-wide impacts of both the FGD and shutdown policies are estimated in the next section.

Table 4 Key variables from the base case simulation

	2005	2010	Growth rate (%)
Population (mil.)	1,308	1,349	0.6
GDP (bil. 2002 *yuan*)	17,926	28,259	9.1
Consumption (bil. 2002 *yuan*)	5,828	9,181	9.1
Energy use (mil. tons sce)	1,529	2,238	7.6
Coal use (mil. tons)	1,509	2,096	6.6
Oil use (mil. tons)	278	460	10.1
Electricity output (bil. kWh)	2,544	3,997	9.0
Transportation (bil. 2002 *yuan*)	1,848	3,409	12.2
Total SO_2 emissions (mil. tons)	25.5	32.3	4.7
SO_2 emissions from electricity sector (mil. tons)	13.3	17.3	5.2
Primary particulate emissions (mil. tons)	9.8	9.0	−1.5
NO_x from transportation (mil. tons)	5.4	8.8	9.8
Carbon emissions (mil. tons)	1,011	1,464	7.4

Source: Authors' calculations.

generation sector are targeted to fall by 25 percent between 2005 and 2010 at the same time that total electricity output is projected to increase by more than 45 percent (IEA 2007).

Economy-wide Impacts of the 11th Five-Year Plan Policies

This section uses a model of the Chinese economy to simulate and examine the impacts the SO_2-reduction policies described in the previous section may have on sectors other than electric power and on the economy as a whole. These impacts include changes in prices, consumption, energy use, economic structure, and growth.

Methodology for the Analysis

We use a CGE model of the Chinese economy to analyze the economy-wide impacts of the Five-Year Plan policies. The model also includes an environmental module. The main data source for the model is the 2002 input–output table for China, which divides the economy into thirty-three sectors, of which nineteen are manufacturing and six are energy sectors (National Bureau of Statistics 2006). A full range of taxes and subsidies are specified in the model, as is the large public sector, which is a characteristic of China's transitioning economy. This model is described in more detail in Cao, Ho, and Jorgenson (2009) in this symposium.

In order to analyze the impacts of the small-unit shutdown and FDG policies on the rest of the economy, we first establish a base case, or "business-as-usual" (BAU) scenario. The BAU scenario includes previous environmental policies, but not the SO_2 policies in the 11th Five-Year Plan. It is assumed that the FGD units already installed in 2005 continue to operate, but that no additional FGD equipment is installed. We then perform simulations of the shutdown and FGD policies using the cost estimates described in the previous section.

The Base Case

Table 4 presents a number of key variables from the base case simulation. GDP and household consumption are projected to grow at about 9 percent per year over the 11th Five-Year

Plan period. Demand for transportation increases rapidly (12.2 percent per year), which causes a 10.1-percent-per-year increase in the demand for oil. Coal use grows less rapidly (6.6 percent per year), but continued electrification causes electricity output to increase at a rate of 9 percent per year during the period. In per capita terms, electricity grows at a rate of 8.4 percent.[15] Without additional controls, total SO_2 emissions are projected to increase by almost 27 percent over the 2005–2010 period.

Impacts of the Small-Unit Shutdown Policy

Because the small-unit shutdown policy is a non-market intervention made by the central government, simulation of the policy in a CGE model requires some departure from a more standard analysis. Also, while the power sector comprises a single sector in the input–output table and in our model, the power generation sector in China is in reality comprised of many different types of technology, including small (higher-cost) thermal-fired plants, larger (lower-cost) thermal-fired plants, hydro, and nuclear power. Some of this market segmentation is the result of implicit and explicit government subsidies. Thus we represent the power sector differently from other sectors in the model. More specifically, instead of having demand for capital in the power sector determined endogenously, based on the market price of capital, we set the capital stock exogenously and derive an endogenous sectoral rate of return that differs from the economy-wide rate of return.

According to the plan for SO_2 control, approximately 50 GW of new power generation capacity will be installed per year from 2006 to 2010, while approximately 10 GW of small thermal-power units will be shut down each year. In the simulation, we represent the reduction in inputs of coal and oil (per kWh of electricity) resulting from this change in the generation technology mix by reducing the energy intensity parameter and shifting the power sector cost function down. We noted in the previous section that the average total cost for small plants is 0.704 *yuan* per kWh compared to 0.250 *yuan* per kWh for large plants. The policy shuts down only 50 GW of small units, while a total of 700 GW of capacity is expected to be in operation by the end of 2010. As a result, the changes in energy cost shares and unit cost are modest, with the energy cost share falling to 22.2 percent in 2010, compared to 22.6 percent in the base case, and the unit cost falling by 9.4 percent in 2010 (see Appendix Table A3).

The higher-cost small generation units exist in part because of implicit and explicit subsidies from the government. In our simulation, we represent the reduction in coal and oil input costs resulting from the shutdown policy as a reduction in subsidies, but we leave the price of electricity unchanged. We then hold all other government expenditure at the same level as in the base case. The reduction in total government expenditure due to the reduction in subsidies is recycled as reductions in taxes. A large literature has shown that the form of revenue recycling can influence the net cost of a policy (see, e.g., Bovenberg 1999). In our simulation, we reduce all tax rates proportionately based on the savings from the subsidy

[15] While the rate of electrification in China may seem high, we note the rapid growth experienced in the United States after World War II. Between 1950 and 1970, U.S. GDP grew at 3.8 percent per year, while electricity use grew at an average rate of almost 8 percent. In per capita terms, U.S. electricity consumption was rising at a rate of 6.3 percent per year. It was not until the second half of the 1970s that U.S. electric power consumption growth fell to match GDP growth.

Table 5 Effects of environmental policies (% change in 2010)

	BAU 2010	Effects of shutdown policy (% change)	Effects of FGD policy (% change)	Effects of combined policies (% change)
GDP (bil. 2002 *yuan*)	28,259	0.55	−0.06	0.48
Consumption (bil. *yuan*)	9,181	0.37	−0.06	0.30
Investment (bil. *yuan*)	10,841	0.79	−0.06	0.72
Government demand (bil *yuan*)	3,788	0.00	−0.04	0.00
Energy use (mil. tons sce)	2,238	−2.94	−0.07	−3.01
Coal use (mil. tons)	2,096	−4.40	−0.08	−4.48
Oil use (mil. tons)	460	−0.12	−0.04	−0.16
Electricity output (bil. kWh)	3,997	−0.26	−0.96	−1.23
SO_2 emissions (mil. tons)	32.3	−7.60	−20.82	−28.42
Primary particulate emissions (mil. tons)	9.0	−3.97	−0.07	−4.04
NO_x from transportation (mil. tons)	8.9	0.44	−0.06	0.38
Carbon emissions (mil. tons)	1,464	−3.26	−0.07	−3.33

Source: Authors' calculations.

removal. Since much of the tax revenue in the base year is derived from taxes on enterprises, as opposed to income taxes (as is the case in the United States), the main beneficiaries of the tax reduction are enterprises. As enterprises use retained earnings to finance some of their investment, the tax reduction leads to an increase in investment.

Given our assumptions about how the implicit government subsidies for the small units are reduced when they are shut down, the price and demand for electricity are essentially unchanged following the shutdown (see Appendix Table A4). The fact that the shutdown policy results in the production of a kWh of electricity with fewer inputs is equivalent to a small positive productivity shock to the economy. Aggregate GDP rises slightly in each year, which in turn results in higher investment. By the end of the Five-Year Plan period in 2010, the combined change in productivity and the larger capital stock results in an increase in GDP of 0.55 percent from the baseline. Household consumption rises by 0.37 percent and total investment by 0.79 percent (see Table 5). As discussed above, government expenditure is assumed to be held constant. Since the effect of the tax reduction is larger for enterprises than for households, the percentage rise in investment is greater than the rise in consumption. This shifts the overall composition of output slightly, with, for example, higher growth in the construction and cement industries than in the service sector.

The reduction in the amount of coal and diesel fuel required to generate an average kWh of electricity results in a decline in total coal and oil consumption, with coal use declining by 4.4 percent and oil use declining by 0.12 percent in 2010 (see Table 5). Part of the reduction in oil use by the electricity sector is offset by a small increase in consumption in other sectors, such as transportation. With the reduction in coal and oil use due to the small-unit shutdown, SO_2 emissions fall by 7.6 percent. In the same year, emissions of particulate matter fall by 4.0 percent. Changes in emissions differ from changes in fuel demand because emissions factors differ by industry and because of shifts in the structure of output.

It is natural to ask why this policy was not implemented earlier, since it would have positive effects on both the environment and the economy. The answer is that the costs and benefits of the policy fall on different segments of the population. As noted above, in many cases small power plants were built in areas that were underserved by the electrical grid and in response to past energy shortages. Closing them would also have negative impacts on local employment. Replacing small plants with larger ones would also require relatively large capital expenditures not easily made by some localities. In many cases there is also likely to be a need for additional transmission capacity after the small plants are shut down. On the other hand, both the economic and environmental benefits are more widely spread. However, the magnitude of the total benefits does argue for transitional assistance (for workers, plant operators, and other affected groups) as part of the implementation of the policy.

Impacts of the FGD Installation Policy

In 2006, 16.7 percent of total electricity output (by kWh) was produced by generation units equipped with FGD (see Appendix Table A5). In keeping with the projected level of capacity and our estimate of total output, the amount of electricity produced by units with FGD installed and operating should increase to 61.9 percent in 2010. Because, as discussed above, operating an FGD unit raises the delivered electricity cost by 1.5 percent, the average cost of all electricity generated rises by approximately 0.25 percent (16.7 percent $\times$ 1.5 percent) in 2006 and 0.91 percent (61.9 percent $\times$ 1.5 percent) in 2010 (see Appendix Table A5). We represent this as an upward shift of the cost function, which is equivalent to a negative productivity shock. That is, the installation and operation of the FGD equipment increases the inputs (capital, labor, and energy) required to generate the same amount of electricity.

When this small increase in costs is simulated in the CGE model, the net effect—including general equilibrium adjustments—is to raise electricity prices, by 0.25 percent in 2006, rising to 0.94 percent in 2010. Given our unit elasticity assumption, this reduces overall electricity use by approximately the same (absolute) percentage as the rise in price. The higher cost of electricity leads to a small decline in the output of energy-intensive industries such as chemicals, non-metal mineral products, and primary metals. The use of FGD also increases the amount of coal required to generate a kWh of deliverable electricity. However, this is offset by the reduction in the demand for electricity and the reduction in the demand for coal by energy-intensive industries, which leads to a small net decline (0.08 percent) in coal consumption in 2010.

This small negative productivity shock results in a slight decline in GDP, with corresponding reductions in the consumption and investment components of GDP (see Table 5). The lower amount of investment in each period results in a smaller capital stock in the subsequent periods. By the end of the Five-Year Plan period, the smaller capital stock and lower productivity results in GDP being about 0.06 percent below the baseline. There is also a slight change in the composition of output with, as noted above, the electricity-intensive sectors declining the most. Output of less electricity-intensive industries such as agriculture and services fall by a smaller amount.

Because it is not electricity intensive, transportation is only slightly affected by the FGD policy. The net effect of reductions in manufacturing and transportation is a 0.04 percent decline in oil consumption in 2010. The effect of the FGD policy on natural gas consumption is small, as most natural gas use is in industry, such as chemical manufacturing. As targeted in the Five-Year Plan, the installation and operation of FGD equipment in the power sector results in an economy-wide decline in SO_2 emissions of more than 20 percent by the end of the plan period. In addition to the abatement carried out through the FGD equipment, part of the reduction in emissions comes about because of an overall reduction in electricity output. Particulate and NO_x emissions fall slightly, in line with the small declines in manufacturing output and transportation.

Combined Impacts of the FGD and Shutdown Policies

Our final simulation combines the small-unit shutdown and FGD installation policies. It is thus our best estimate of the overall impacts of the 11th Five-Year Plan's SO_2 reduction policies—if they are fully implemented. As shown in Table 5, the impacts are essentially additive. In our simulation, GDP in 2010, the last year of the plan, is 0.48 percent above the baseline. This is due primarily to the productivity improvement and increase in capital stock resulting from the small-unit shutdown, which offsets the slight decline in GDP resulting from the installation of the FGD equipment.

The combined effect of the policies on SO_2 is a reduction of emissions in 2010 of 28.4 percent from the baseline, which would achieve the Five-Year Plan target. The small net increase in transportation results in an increase in NO_x emissions of 0.38 percent. These results demonstrate some of the value of analyzing policy in an economy-wide framework, as the net environmental effects of a policy differ from the estimated effects on individual sectors. Given concerns about China's contribution to greenhouse gas emissions, we also calculated the effect of the two policies on CO_2 emissions, which are estimated to fall by slightly more than 3 percent (see Table 5).

We should note that our model does not currently incorporate endogenous feedback of damages to human health and ecosystems from exposure to pollution. If we included the effects of pollution on labor productivity and agricultural output, the two Five-Year Plan policies might have further positive effects on the economy.

Summary and Conclusions

China's 11th Five-Year Plan marks a major departure from previous plans. Particularly notable is the increased focus on energy and environmental issues. The energy and environmental targets in the plan are ambitious and will require a significant effort on many levels if they are to be achieved. This article has examined the SO_2 reduction target in the 11th Five-Year Plan and analyzed the economic and environmental impacts of two major policy measures designed to achieve this target. Based on simulations using an economy-wide model, we find that one of the measures—the shutdown of 50 GW of small power plants—would have unambiguously positive long-run impacts on the economy and the environment. The second policy—the installation of FGD equipment on new and existing power plants—would impose some modest economic costs.

In the aggregate, the economic benefits of the shutdown policy easily offset the costs of installing and operating the FGD equipment. The net economic benefits of the combined policies are large enough that they could—and should—be used to compensate the localities that will be negatively affected by the small power plant closures. Our results go beyond the U.S.–China Joint Economic Study (JES), which only compared the direct costs of FGD installation with the health benefits of improved air quality. The JES found substantial benefits from the air quality improvements. However, neither the JES nor our economy-wide analysis fully accounts for all of the economic benefits of reducing SO_2 emissions.

Although it is too early to make an assessment of the likelihood of success of the Five-Year Plan's policies, there have been some positive signs. It has been reported that in 2007, the first year the shutdown policy was fully in effect, small power plants with a total capacity of 14.38 GW were shut down (*China Daily*, August 20, 2008). In addition, after climbing slightly in 2006, total emissions of SO_2 fell to 24.68 million tons in 2007, which is more than 3 percent below the level in 2005 (SOE 2007). Only time will tell if China will follow through on these encouraging trends to successfully achieve the 2010 target for SO_2 emissions.

Appendix

Table A1 10th Five-Year Plan for environmental protection: major targets vs. performance

		2000	2005		
No.	**Indicator**	**Base**	**Target**	**Actual**	**Attained/Not attained**
1	SO_2 emissions (mil. tons)	19.95	18.00	25.49	Not attained
2	Emissions of smoke and dust (mil. tons)	11.65	11.00	11.83	Not attained
3	Industrial dust (mil. tons)	10.92	9.00	9.11	Not attained
4	COD (mil. tons)	14.45	13.00	14.14	Not attained
5	Industrial solid waste (mil. tons)	31.86	29.00	16.55	Attained
6	Reuse rate of industrial water (%)	–	60	75	Attained
7	Industrial SO_2 (mil. tons)	16.13	14.5	21.68	Not attained
8	Emissions of industrial smoke and dust (mil. tons)	9.53	8.50	9.49	Not attained
9	Industrial COD (mil. tons)	7.05	6.50	5.55	Attained
10	Comprehensive use rate of industrial solid waste (%)	51.8	50.0	56.1	Attained
11	Percent of cities meeting Grade II national standard (%)	36.5	50.0	54.0	Attained
12	Urban sewage treatment rate (%)	34.3	45.0	52.0	Attained
13	Green coverage of urban built-up areas (%)	28.1	35.0	33.0	Not attained
14	Percentage of land area in nature reserves (%)	9.9	13.0	15.0	Attained

Source: SEPA (2007).

Table A2 Cost structure for thermal power plants, 2005 (*yuan*/kWh)

		Small plants		
Costs	**Large plants**	**Total**	**Coal**	**Diesel**
Average total cost	0.250	0.704		
Operating & maintenance cost	0.057	0.068		
Fuel costs	0.153	0.596	0.230	2.520

Source: Energy Research Institute.

Table A3 Economics of the small plant shutdown policy

Year	Total electricity output (bil. kWh)	Thermal electricity output (bil. kWh)	Small plant electricity output (bil. kWh)	Original energy cost share (%)	Energy cost share after shutdown (%)	Reduction in cost per kWh (%)
2005	2,544	2,083	400	23.8		
2006	2,742	2,247	360	23.6	23.4	−2.4
2007	2,956	2,424	320	23.3	23.1	−4.5
2008	3,187	2,616	280	23.1	22.8	−6.4
2009	3,435	2,824	240	22.8	22.5	−8.0
2010	3,703	3,048	200	22.6	22.2	−9.4

Sources: IEA (2007) and authors' calculations.

Table A4 Effects of policies on energy sectors (% change from base case)

	Coal		Oil		Electricity	
Year	Use (%)	Price (%)	Use (%)	Price (%)	Use (%)	Price (%)
Shutdown policy						
2006	−1.29	−0.15	−0.05	−0.11	−0.10	0.00
2007	−2.21	−0.29	−0.07	−0.21	−0.16	−0.01
2008	−3.06	−0.35	−0.09	−0.26	−0.21	−0.01
2009	−3.79	−0.42	−0.12	−0.31	−0.24	−0.02
2010	−4.40	−0.47	−0.12	−0.35	−0.26	−0.03
FGD policy						
2006	−0.02	0.02	−0.01	0.02	−0.26	0.25
2007	−0.04	0.04	−0.02	0.03	−0.48	0.47
2008	−0.05	0.05	−0.03	0.04	−0.67	0.66
2009	−0.07	0.06	−0.03	0.05	−0.83	0.81
2010	−0.08	0.07	−0.04	0.06	−0.96	0.94
Combined shutdown and FGD policies						
2006	−1.31	−0.13	−0.07	−0.09	−0.36	0.25
2007	−2.25	−0.25	−0.09	−0.17	−0.65	0.46
2008	−3.12	−0.30	−0.12	−0.21	−0.88	0.64
2009	−3.86	−0.35	−0.16	−0.25	−1.07	0.79
2010	−4.48	−0.40	−0.16	−0.29	−1.22	0.91

Source: Authors' calculations.

Table A5 Economics of the FGD policy

Year	Total FGD installed (GW)	FGD installed under 11th FYP (GW)	Total electricity output (bil. kWh)	Thermal-fired electricity output (bil. kWh)	Output covered by 11th FYP FGD (bil. kWh)	FGD under 11th FYP (% of total kWh)	Increase in average cost following installation of FGD (%)
2005	46		2,544	2,083			
2006	130	83	2,742	2,247	459	16.7	0.25
2007	213	83	2,956	2,424	917	31.0	0.46
2008	296	83	3,187	2,616	1,376	43.2	0.63
2009	380	83	3,435	2,824	1,835	53.4	0.78
2010	463	83	3,703	3,048	2,294	61.9	0.91

Source: IEA (2007) and authors' calculations.

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Abstract

China's rapid economic growth has been accompanied by a high level of environmental degradation. One of the major sources of health and ecosystem damages is sulfur dioxide (SO_2). Reducing SO_2 emissions is a priority of China's environmental authorities, and the 11th Five-Year Plan (2006–2010) includes the target of reducing total SO_2 emissions by 10 percent from the 2005 level. Given the rapid increase in SO_2 emissions that is expected to occur in absence of intervention, attaining this target will require a significant effort. This article examines the two major policy measures the government is taking to achieve the SO_2 target: a shutdown of many small, inefficient power plants and the installation of desulfurization equipment on existing and new coal-fired plants. We present results from a joint U.S.–China study that we participated in, which estimated the costs and benefits of these policies. We then estimate the economy-wide impacts of the two policies using a multisector model of the Chinese economy. We find that in the aggregate, the economic benefits of the shutdown of the small power plants are large enough to offset the costs of the desulfurization equipment, even without considering the substantial environmental benefits from the reduction of emissions of SO_2 and other pollutants. (*JEL*: D58, Q53, Q58)