UNIVERSITY OF SOUTHERN QUEENSLAND

Achieving Carbon Reductions in the Chinese Economy: An Examination of Policy Options

A dissertation submitted by

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Abstract

As the world largest carbon dioxide (CO_2) emitter, China is under pressure to develop policies to mitigate carbon emissions, with market-based approaches under consideration. Emissions trading is theoretically the most efficient approach but some countries are starting with carbon/energy taxes. This research examines these two options through literature and practice in order to evaluate which might be most suitable for China and then to estimate the major economic impacts of the selected option.

The thesis first looks at the limited cases of emissions trading, with a particular focus, using official reports and data and interviews, on the example of SO_2 control in Taiyuan city. It is found that the Taiyuan SO_2 emissions trading program does not seem to be functioning anything like the ideal emissions trading model and cannot be judged as a successful scheme in terms of emissions reductions, cost savings, innovation and investment in clean energy, and investment leakage. When combined with concerns about the limited development of truly free markets and the weak law basis in China, it is concluded that emissions trading may not be the best policy option at this stage and that a carbon tax might be the most practical interim measure.

Next, the impacts of a carbon tax are considered through a computable general equilibrium (CGE) model for China. The simulation results show that overall the introduction of a carbon tax will have a negative impact on the economy, but this negative impact is relatively gentle if considered against the emissions reductions. After a carbon tax is imposed, carbon intensive sectors will suffer most seriously and there will be a shift away from high-carbon factors toward low-carbon or non-carbon factors. Moreover, the adverse effects of the tax on economy could be relieved to some extent by subsidizing households, through transfers of the tax revenue. From the experience of Australia, China could also use carbon tax as a transitional policy and then move to carbon emissions trading system when the market mechanism becomes mature.

Certification of dissertation

I certify that the ideas, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

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Signature of candidate Date

Endorsement

Signature of Supervisors Date

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Publications

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List of abbreviations and acronyms

ADB	Asian Development Bank
bbl/d	Thousand barrels per day
CAEP	Chinese Academy for Environmental Planning
CDM	Clean development mechanism
CEM	Continuous Emission Monitoring
CES	Constant elasticity of substitution
CGE	Computable General Equilibrium
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CPRS	Carbon Pollution Reduction Scheme
EDF	The US Environment Defense Fund
EIA	The US Energy Information Administration
EJ	Etajoules
EPA	The US Environmental Protection Agency
EPB	Environmental Protection Bureau in China
ETS	Emissions trading scheme
EU	European Union
EU ETS	European Union Emissions Trading Scheme
GDP	Gross Domestic Product
GHGs	Greenhouse gases
GW	Gigawatt
IEA	International Energy Agency
I/O	Input-output
IPCC	Intergovernmental Panel on Climate Change
JI	Joint implementation
MPC	Marginal propensity to consume
Mt	Million tonnes
Mtce	Million tonnes of coal equivalent
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
NDRC	National Development and Reform Commission of the People's

	Republic of China
NGOs	Non-government organizations
NO_X	Nitric oxide
OECD	Organization for Economic Cooperation and Development
R&D	Research and Development
RFF	Resources for the Future
SAM	Social accounting matrix
SEPA	Chinese State Environmental Protection Administration
SO_2	sulphur dioxide
t	Tonnes
tce	Tonnes of coal equivalent
toe	Tonnes of oil equivalent
TEC	Total emission control
TWh	TeraWatt hours
UK	United Kingdom
US	United States
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value-added tax

Chapter 1 Introduction

1.1 Background

Climate change, the topic of this research, has become a major concern in the world (Stern 2007). It refers to ‘a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer’ (IPCC 2007a, p. 943). The average temperature of the earth has increased 0.7℃ since 1900 (Brohan et al. 2006). There have been global sea level increases, consistent with warming, at an average rate of 3.1 mm per year from 1993 to 2003, compared with 1.8 mm per year from 1961 to 2003 (IPCC 2007b). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concludes that ‘warming of the climate system is unequivocal’ (IPCC 2007b, p. 30).

The impact of climate change is wide and serious. Climate change leads to agricultural change, infrastructure damage and human health deterioration (Pearce & Turner 1990). According to the World Trade Organization, an increase in temperature of 1℃ above the pre-industrial level could lead to at least 300 000 people dying from climate change effects annually (Patz et al. 2005). With an increase of 2℃, about 15–40% of species will become extinct, cereal production will decrease by 5% under weak carbon fertilization and 1–4 billion people will experience water shortages (Stern 2007). Even at more moderate levels of warming, climate change will impact seriously on world output, human life and the environment (Stern 2007).

Climate change is mainly due to the increase in greenhouse gases (GHGs) caused by human activities (Garnaut 2008). Fossil fuel use and land use changes play significant roles in the global concentration of carbon dioxide (IPCC 2007b; CO_2). The GHGs described by the Kyoto Protocol include carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons (Commonwealth of Australia 2008). They absorb thermal infrared radiation and trap some of the heat from the earth’s surface, which in turn increases the temperature of the planet (Hengeveld & Bush 2008; Pearce & Turner 1990). Hereinafter these emissions are referred to as 'carbon emissions' for convenience.

Observed evidence of climate change in China is also obvious. The annual average temperatures in the North China Plain and north-eastern China increased 0.20℃ and 0.27℃ per decade respectively over the past 50 years (Shen & Varis 2001). As a developing country, China is considered likely to be one of the worst-affected regions in the world by climate change (IPCC 2007a). Because of drought caused by global warming, agricultural production in China could be reduced by 5–10% by 2030, thus adding stress to a country with 20% of the world's population but only 7% of the arable land (The People's Republic of China 2007; Zeng et al. 2008).

In order to tackle the threat of global climate change, the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol in 1997; it came into force in 2005. In the Kyoto Protocol, Annex I countries[1] have committed to reducing carbon emissions over the period 2008–2012 by 5.2% below the level attained in 1990, while no such commitment has been taken by developing countries (UFCCC 1998). The Kyoto Protocol also provides three kinds of 'flexible mechanisms' for countries to comply with their targets: emissions trading, joint implementation[2] (JI) and the clean development mechanism[3] (UFCCC 1998; CDM).

Carbon emissions in China have shown an increasing trend over the last 50 years, particularly during the urbanization and industrialization periods of the last two decades (Feng et al. 2009; Guan et al. 2008). Moreover, China overtook the United States (US) and became the world's largest CO_2 emitter in 2006 (Netherlands Environmental Assessment Agency 2007). Thus it is expected that China, as a large emitter, should take on future targets to mitigate GHG emissions (Environmental Resources Management 2007). During the Copenhagen Summit 2009, China insisted on 'common but different responsibilities' between developing and developed

[1] Annex I countries refer to the Organization for Economic Co-operation and Development (OECD) countries and countries with economies in transition. These countries have committed themselves to GHG emissions targets.

[2] 'A market-based implementation mechanism defined in Article 6 of the Kyoto Protocol, allowing Annex I countries or companies from these countries to implement projects jointly that limit or reduce emissions or enhance sinks, and to share the Emissions Reduction Units' (IPCC 2007c, p. 817).

[3] 'Certified Emission Reduction Units from CDM projects undertaken in Non-Annex 1 countries that limit or reduce GHG emissions, when certified by operational entities designated by Conference of the Parties/Meeting of the Parties, can be accrued to the investor (government or industry) from parties in Annex B' (IPCC 2007c, p. 811) .

countries, and made a voluntary commitment to reduce carbon emissions per Gross Domestic Product (GDP) by 40–45% below its 2005 level in 2020 (Wen 2009).

China attaches great importance to climate change and has made efforts to address the issue (Song 2009). By analysing the contributions to CO_2 emissions growth between 1980 and 1997 in China, Zhang (1998b) concludes that even though the total amount of CO_2 emissions is increasing due to economic growth and population expansion, China has made significant contributions to reducing global CO_2 emissions through cutting energy intensity. He summarizes four reasons for combating global climate change in China's interest:

> (1) Climate-sensitive sectors such as agriculture still account for a much larger proportion of GDP in China than in the developed countries; (2) China is scarce in energy, with per capita energy endowments far below the world average; (3) China is already determined to push energy conservation and enhanced energy efficiency in general and more efficient coal usage in particular. (4) Limiting GHG emissions will contribute to the reductions in local pollutants and thus will be beneficial to a more sustainable development of the Chinese economy (Zhang 1998b, pp. 17-18).

In summary, due to the broad and serious impacts of human-induced climate change, it is clear that combating carbon emissions is in the interest of all human beings. As the largest CO_2 emitter in the world, China is facing increasing domestic and international pressure to set a good example in mitigating carbon emissions and reducing carbon emissions is in China's best interests.

1.2 Statement of the problem

'Climate change is an example of market failure involving externalities and public goods' (Stern 2007, p. 25), therefore it cannot be corrected by the market itself. Usually four types of policies are considered for addressing environmental issues: regulation, Pigovian subsidies, Pigovian taxes and tradable permits (Daly & Farley 2004). Regulation is a rule or directive made and maintained by an authority. A Pigovian subsidy refers to a subsidy provided to an activity on the grounds that the activity generates positive externalities, while a Pigovian tax is a tax levied on a market activity that generates negative externalities. A tradable permit is a licence, granted by a government, to pollute that can be bought and sold.

Regulation and subsidies are not popular among market-oriented economists (Pearce & Turner 1990). For them, the preferred economic instruments for meeting the carbon emission targets are an emissions trading scheme (ETS) or a carbon tax. These two market-based methods generate debates among economists (Stavins 2008). Cramton and Kerr (2002) recommend that permit trading systems, being transparent, may be more politically desirable than carbon taxes. Soleille (2006) believes that emissions trading schemes can be the most cost effective if there is the necessary political will and are designed and implemented properly. Furthermore, Akhurst et al. (2003) and Ellerman et al. (2003) suggest that emissions trading is suitable for solving the GHG emissions problem as a tonne of a given GHG will have the same effect on atmospheric concentration regardless of where it is emitted or mitigated, and the cost of reducing GHG emissions varies widely among sources and across countries. In contrast, Pizer (2002) argues that it would be preferable to use a tax to control carbon emissions, and he finds tax instruments produce six times the expected net gains of the most well-designed emission trading mechanisms by taking into account both the potential long-term climate change loss and the GHGs control cost.

China mainly uses command-and-control regulation to control carbon emissions (The State Council of the People's Republic of China 2009), but there is an increasing consideration of whether a more effective carbon reduction policy should be introduced. Cooper (2005) and the Research Institute for Fiscal Science, Ministry of Finance in China (2009) suggest a carbon tax, while Tu (2008) and Raufer & Li (2009) support emissions trading. However, these suggestions were delivered as statements rather than as arguments explaining why either policy might be best in the Chinese context.

Research on the suitability of the emissions trading system for China to reduce carbon emissions has been underdeveloped and the design features that could maximize carbon reductions remain largely unknown in the Chinese context. According to emissions trading theory and existing practices, several major elements such as targets, coverage, banking, borrowing and penalties need to be considered before the implementation of such a system. If, however, a carbon tax policy is more appropriate for China then sufficient evidence should be gathered to support this.

In summary, the carbon emissions problem considered here is not whether mitigation is important, but rather how to mitigate. However, at this stage, it is difficult to assert which economic instrument is more effective in reducing carbon emissions in China in the absence of large-scale applications and rigorous analysis. This research attempts to address this issue by documenting one of China's existing emissions trading practices and evaluating which instrument may be most suitable at this stage.

1.3 Motivation for this research

As noted in the previous section, anthropogenic climate change is a serious problem and China is a major contributor to this problem. China has been and will be seriously affected by the consequences. Research that leads to the most appropriate policy response is thus critical.

Although there is some evidence to support the use of tradable permits or cap-and-trade programs, much of the research has involved sulphur dioxide (SO_2) emissions in the US (Field & Field 2006), where programs have been running for some time. Worldwide there is also a growing interest in the carbon emissions trading pioneered in Denmark and the European Union Emissions Trading Scheme (EU ETS), which is so far the largest system of its kind (Ekins & Barker 2002; Soleille 2006). However, China still heavily relies on command-and-control regulation such as shutting down the seriously polluting enterprises, which usually involves high costs to the firms and society (The State Council of the People's Republic of China 2009). It is therefore necessary for China to consider adopting a more cost-effective policy. But at the current stage of China's political and economic development, whether or not a market-based policy could work in China remains unknown. Therefore, this research is motivated by the wish to find a solution for China to meet its carbon reductions target by learning from international practice and considering its own special situation.

1.4 Research objectives and questions

This research has two main objectives. The first is to assess whether emissions trading is likely to be effective in reducing carbon emissions in China. This will be examined by looking at the existing emissions trading practice in China, collecting

GHGs perspectives from experts and considering the literature on experiences elsewhere. If carbon emissions trading is found to be effective for China, then the design features of a Chinese carbon emissions trading system can be proposed; otherwise, an alternative economic instrument such as a carbon tax regime needs to be considered.

Therefore, the main research question to be investigated is:

What policy option should China adopt to achieve carbon reductions?

To answer this question several sub-questions are explored:

Q1: Is emissions trading a suitable policy for achieving carbon reductions in China?
If so
Q2: What design features of a carbon trading system would maximize emission reductions in China?
If not
Q3: Is carbon tax a suitable policy for achieving carbon reductions in China?

This last question will be considered by examining the impacts of a carbon tax, including emissions reductions and economic effects.

1.5 Scope of this research

This research focuses on environmental policy for mitigating carbon emissions in China. Most of the discussion will be on the possible economic instruments for mitigating carbon emissions, the suitability of emissions trading to help China achieve carbon reductions, and the decisions on the main features of a carbon trading system in the Chinese context (if applicable). It will not only review existing carbon trading practices around the world, but also investigate other emissions trading programs, in particular the SO_2 emissions trading program in Taiyuan city, China. A carbon tax will be considered as an alternative policy if emissions trading is judged not suitable at this time. In that case, the rest of the research will focus on quantifying the effects of a carbon tax in China through a computable general equilibrium (CGE) model.

The instruments for reducing carbon emissions discussed in this research are limited to command-and-control regulation and market-based policies, excluding the development of new technology to enhance energy intensity and changes in energy production, transportation, land use and natural resources policies. The emissions trading schemes mentioned in this study particularly refer to cap-and-trade programs, not including credit-based and averaging programs. The various emissions trading types are elaborated in Table 1.1.

Table 1.1 The three main types of emissions trading programs

Program Type	Definition	Example
Cap and Trade program	A market-based policy tool that establishes an aggregate emission cap on total emissions from a group of sources and creates a financial incentive to reduce emissions. The emission cap is expressed as allowances distributed to individual emission sources that must surrender allowances to cover their emissions.	EU ETS
Project-based, Credit or Offset Program	An emission reduction of a specific quantity of a pollutant (e.g., 1 tonne) verified through a project-based trading program. An offset can be applied to regulatory emission limits as an authorization to emit that specific quantity of pollutant.	CDM, JI
Rate-based or Averaging program	A trading approach in which the regulating authority determines an emission rate performance standard (i.e., an amount of emissions allowed per unit of heat input or product output) for a sector (e.g., tonnes/kWh) and allows sources that over-and under-comply with the standard to trade credits.	American lead in gasoline and heavy-duty engine emission standards programs New South Wales Greenhouse Gas Reduction Scheme

Data source: adapted from EPA (2003a, pp. Glossory 2 - Glossory 4)

1.6 The structure of the thesis

The overall logic for this thesis can be summarized as follows (Figure 1.1). The policy options for mitigating carbon emissions are reviewed to suggest that emissions trading is theoretically the most effective policy instrument for reducing carbon emissions (Chapter 2). Being the world’s largest CO_2 emitter, China is under increasing pressure to mitigate carbon emissions. Thus research Q1, ‘*Is emissions trading a suitable policy for achieving carbon reductions in China?*’, is proposed in Chapter 3. In order to answer research Q1, the case study research method designed to investigate the Taiyuan SO_2 emissions trading program is presented in Chapter 4, along with the collected experts' views on using carbon emissions trading in China. It is found that China may not be ready for a carbon emissions trading system in the short run (Chapter 5).

Then an alternative policy instrument carbon tax is considered. Thus the research Q3 is proposed: '*Is carbon tax a suitable policy for achieving carbon reductions in China?*' (Chapter 5). To examine this question, a Chinese carbon tax CGE model is developed to assess the effectiveness of a carbon tax in China (Chapter 6). It is found that the carbon tax is an effective policy in China as it can significantly decrease carbon emissions and does not dramatically impede economic growth. Meanwhile, the energy consumption structure can be improved (Chapter 7). Therefore, it is suggested that China should adopt a carbon tax for controlling carbon emissions in the short term, and transfer to a carbon emissions trading system gradually in the long term (Chapter 8).

Specifically, Chapter 1 provides the background, the motivation, the research objectives and research problems as well as the scope of this study. Chapter 2 reviews the literature in the area of policy options for mitigating carbon emissions, which include command-and-control regulations, subsidies, carbon tax and emissions trading. Chapter 3 is an institutional chapter describing China's energy consumption, carbon emissions and climate change situation, existing policy in controlling carbon emissions, emissions trading practice and the necessary considerations for using carbon emissions trading policy. The case study and interview research methods employed in this study are explained in Chapter 4. Chapter 5 presents the results of the case study and interviews with experts, and discusses the suitability of using emissions trading to achieve carbon reductions in China.

Chapter 6 develops a Chinese carbon tax CGE model to simulate the effectiveness of a carbon tax in reducing carbon emissions and its impacts on Chinese economy, as well as on its energy consumption structure. The chapter begins with a justification for using the CGE approach in this research, and then describes the model equations, followed a discussion of the data and software solutions for the model. Chapter 7 presents the results from the CGE model, and the major findings from the simulations are discussed. Chapter 8 is a summary of the findings, policy implications, contributions, limitations and suggestions for future research.

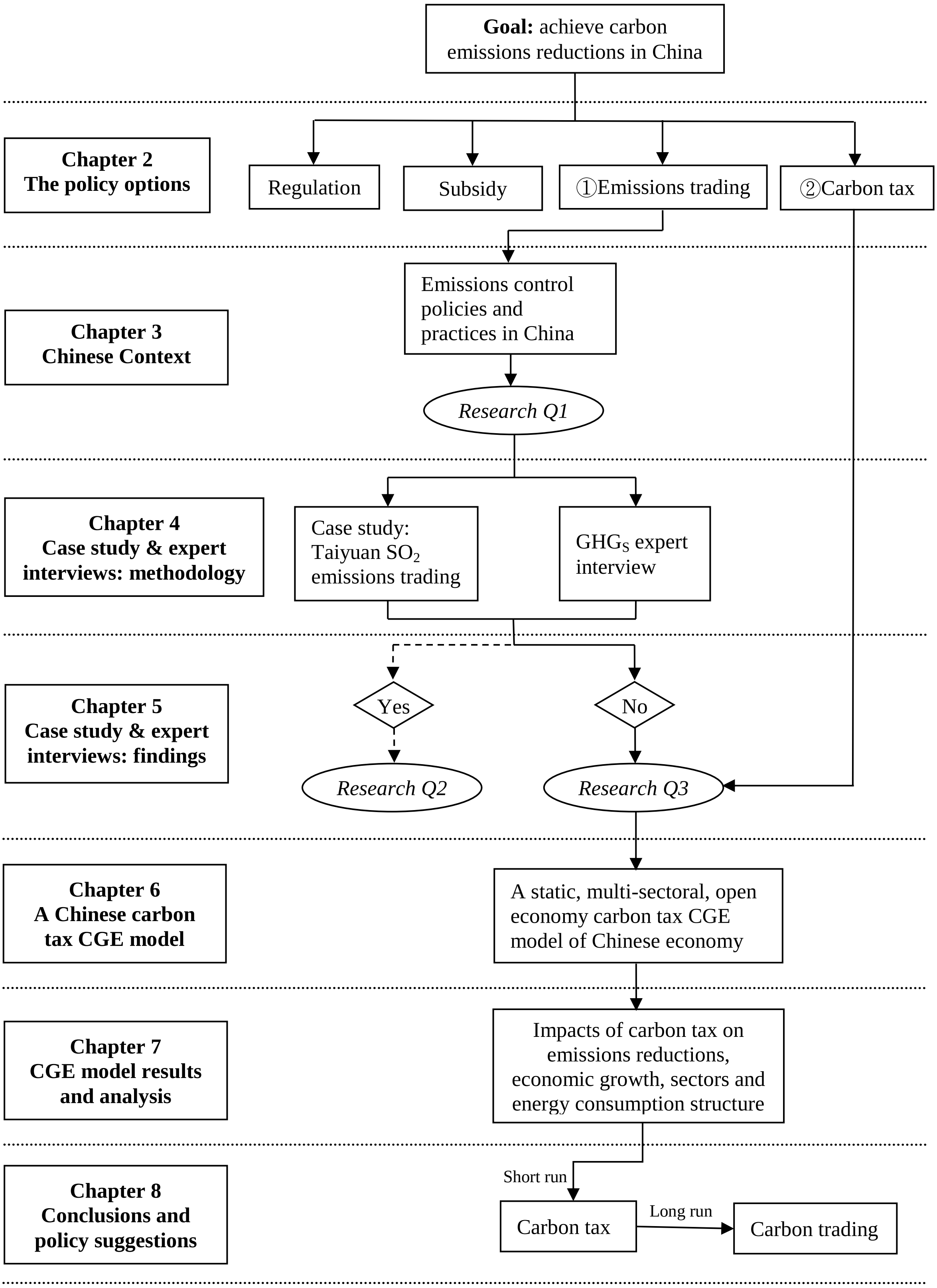


Figure 1.1 Thesis framework

Chapter 2 Review of policy options for mitigating carbon emissions

2.1 Introduction

'Public goods are products or services that are enjoyed in common, such as defense and air (clean or dirty)' (Sterner 2003, p. 2). As a 'global public good', degradation of the atmosphere becomes a 'tragedy of the commons' as espoused by Lloyd (1833) and elaborated by Hardin (1968), where emissions are not restricted by any laws and every emitter believes that he/she has the right to emit. However, when consumers and producers emit into the atmosphere without any compensation, a cost is imposed on the rest of society as an 'externality' (FitzRoy & Papyrakis 2010). It is believed that GHG[4] emissions result in climate change and a loss of welfare for society. Therefore, they are negative externalities (Daly & Farley 2004). Where there is a 'global public good' and an 'externality', the free market does not result in optimal welfare (Sterner 2003). Anthropogenic climate change has therefore been described as the greatest market failure of all (Stern 2007).

Several policy options are available for a government to correct the market failure of climate change. Some political scientists believe that there are three basic categories of policy instruments, 'carrots, sticks and sermons', which stand for economic incentives, legal instruments and informative instruments respectively (Bemelmans-Videc et al. 2003). Generally, the main policy options for reducing emissions are well known: regulations such as emission standards, subsidies for alternatives, carbon taxes and related tradable permits for carbon emissions (FitzRoy & Papyrakis 2010). This chapter reviews these four major types of policies that can be used to mitigate carbon emissions.

This chapter will review the theory, practice and empirical studies or impacts of command-and-control regulations, subsidies, carbon taxes and emissions trading. Especially, an emissions trading market, key elements of a well-designed program,

[4] Hereinafter is referred to as 'carbon emissions' to match the short forms of 'carbon tax' and 'carbon emissions trading'.

and lessons from early trading schemes for national carbon trading scheme will be discussed in section 2.6. Section 2.7 will discuss the criteria for choosing an appropriate policy for controlling climate change and compare the four policy options from different aspects. Some concluding remarks will be offered in section 2.8.

2.2 Command-and-control regulations

2.2.1 The case for command-and-control regulations

The setting of regulations is the traditional approach for addressing market failure due to environmental externalities (Field & Field 2006). Command-and-control regulation refers to a policy that relies on permission, prohibition, standards setting and enforcement. Failure to comply with the regulations generally leads to fines or other penalties (Daly & Farley 2004). Conventionally, command-and-control regulations achieve certain environmental goals by imposing uniform standards on firms through licensing and monitoring (Sandu 2007; Stavins 2003). These standards are either technology-based (by specifying methods or even equipment that firms must use to abate pollution or emissions) or performance-based (i.e., specific limits on emissions) (Stavins 2003; Sterner 2003).

Command-and-control regulations can be an effective policy for addressing market failures and barriers associated with information, organization and other transactions costs (Bashmakov & Jepma 2001). They are reasonably easy to understand, can be monitored and enforced fairly cheaply and applied to everyone equally (Daly & Farley 2004). Environmental administrators prefer (or used to prefer) command-and-control instruments as they can be introduced readily and appear to provide predictable environmental effectiveness and certainty for polluters (Opschoor & Turner 1994). In addition, environmental administrators may have a relatively high preference for regulations because they are familiar with using this option (Opschoor & Turner 1994). However, there are several flaws associated with this approach. First, it does not provide certainty in regard to the costs and the amount of emissions reductions (Nielson 2010). Second, it is deficient in flexibility and motivation and does not provide market signals that would encourage the uptake of cost-effective options for reducing emissions (Armstrong 1998; Owen 1992; Pearce 1991; Sandu

2007), such as developing or adopting clean technology (Stavins 1997). Third, setting the level of regulation is rather difficult (Parry & Pizer 2007). Finally, command-and-control regulations tend to enlarge the domain of bureaucratic control, which adds to the cost of government (Uzawa 2003).

2.2.2 The practice of command-and-control regulations

In the 1970s, in the early stages of environmental policy development, command-and-control regulations were popular in the US (Harrington & Morgenstern 2004; Stuart 2006). The Resource Conservation and Recovery Act and the Clean Air Act are prime examples of regulations to promote environmental quality (Stuart 2006). However, economic incentive instruments have been used more frequently since the late 1980s (Harrington & Morgenstern 2004). This is perhaps due to the growing awareness of economic incentive approaches among policymakers and policy analysts between 1970 and 1990, and the consequent emergence of tradable emissions permits in the late 1970s, following the widespread disappointment with outcomes of the command-and-control regulations adopted in the 1970s (Harrington & Morgenstern 2004).

Most members of the International Energy Agency (IEA) have employed environment-related regulatory standards to reduce carbon emissions. For example, the fuel efficiency standards or requirements to generate a certain amount of renewable energy by a certain date (IEA 2010b). California is a good example (Air Resources Board 2009). A de facto technology standard was enacted in Californian legislation in 2007 (Californian Senate Bill 1368), which prevents the state's utilities having long-term contracts with generators emitting more than 1100 pounds of CO_2/MWh of electricity output (Natural Resources Defense Council 2007; Nielson 2010). In 2009 Australia reduced GHGs and private costs by simply banning inefficient incandescent light bulbs (FitzRoy & Papyrakis 2010).

Some command-and-control regulations were opposed by the business lobbies who argued that the command-and-control regulations (e.g., standards) would lead to large losses of jobs and market share (FitzRoy & Papyrakis 2010). Campaigns for weaker requirements, or postponement of their introduction, are often successful. For example, after the industry failed to meet voluntary targets, proposed tough restrictions on carbon emissions for new cars in 2007 were resisted by the manufacturers of the largest and most polluting cars in Germany and by their political allies (FitzRoy & Papyrakis 2010).

2.2.3 Empirical studies of command-and-control regulations

Energy efficiency standards have been proposed as an effective energy conservation policy instrument, especially in countries with low energy prices (Bashmakov & Jepma 2001). The introduction of an appliance energy performance standard in the US was estimated to save a total of 24 EJ of energy, US$46 billion in consumer life-cycles costs and to reduce 400 Mt CO_2 emissions from 1990 to 2010 (McMahon 1992). For the refrigerator and freezer standards in the EU, cumulative electricity savings were estimated at 300 TWh from 1995 to 2000 (Lebo & Szabo 1996). Similar standards in Central and Eastern Europe were expected to generate 60 TWh of energy savings and 25 Mt CO_2 emissions reductions (Bashmakov & Sorokina 1996). A maximum of 140 Mt CO_2 was expected to be reduced in Japan due to the effectiveness of the law on the rational use of energy in April 1999 (Bashmakov & Jepma 2001). IEA confirmed that the building codes in the residential sector in France, which were set in 1974 and made stricter in 1982 and 1988, led to 75% of the total energy savings over the past 20 years (Bashmakov & Jepma 2001). Overall, when taking into account the history, technology and institution, technology standards are considered an effective approach for the early stages of environmental policy development (Cole & Grossman 1999).

While the effectiveness of energy efficiency standards on energy conservation is recognized, numerous empirical studies suggest that the command-and-control approach is not as cost effective as other economic instruments. The Australian Bureau of Agricultural and Resource Economics estimates that the implementation of a regulatory approach in Australia, such as an 11% mandatory renewable target for electricity generation, along with a 27% fuel efficiency improvement in transport by 2030, leads to twice the cost in GDP reduction than would be the case with a well-designed ETS in achieving the same emissions reductions (Prime Ministerial Task Group on Emissions Trading 2007). Several simulation models of evaluating the cost effectiveness of the command-and-control strategy have been constructed for different pollutants for a variety of metropolitan areas (Table 2.1). As comparing the emissions costs among different research is not reasonable, Tietenberg (2004, p. 269) proposes to calculate 'the ratio of command and control (CAC) allocation costs to the lowest cost of meeting the same objective for each study'. For example, according to Seskin et al. (1983), to reduce nitrogen dioxide in Chicago, the CAC costs are estimated to be 14.4 times more expensive than the alternative least-cost approach.

Table 2.1 Empirical studies of command-and-control regulations

Study and Year	Pollutants Covered	Geographic Area	CAC Benchmark	Ratio of CAC Cost to Least Cost
Atkinson and Lewis (1974)	Particulates	St Louis metropolitan area	SIP regulations	6.00
Roach et al. (1981)	Sulphur dioxide	Four corners in Utah, Colorado, Arizona, and New Mexico	SIP regulations	4.25
Hahn and Noll (1982)	Sulphates	Los Angeles standards	California emission	1.07
Krupnick (1986)	Nitrogen dioxide	Baltimore regulations	Proposed RACT regulations	5.96
Seskin et al. (1983)	Nitrogen dioxide	Chicago	Proposed RACT regulations	14.40
McGartland (1985)	Particulates	Baltimore	SIP regulations	4.18
Spofford (1985)	Sulphur dioxide	Lower Delaware Valley	Uniform percentage reduction	1.78
	Particulates	Lower Delaware Valley	Uniform percentage reduction	22.00
Maloney and Yandle (1984)	Hydrocarbons	All domestic Du Pont plants	Uniform percentage reduction	4.15
O'Ryan (1996)	Particulates	Santiago, Chile	PER/APS	1.31

Definitions: APS = Ambient permit system
CAC = Command-and-control, the traditional regulatory approach
PER = Percentage emission reduction
SIP = State implementation plan
RACT = Reasonable available control technologies, a set of standards imposed on existing sources in nonattainment areas

Source: adopted from Tietenberg (2004, p. 269).

In achieving the same amount of reduction of CO_2 emissions, it has also been confirmed that command-and-control regulations are less cost effective than other economic instruments. Beuusejour et al. (1995) find emission standards on four industries (iron and steel, electric utilities, transportation and services) lead to 33% more GDP loss than an energy tax in stabilizing Canada's CO_2 emissions at the 1990 levels in the year 2000. Shrum (2007) concludes that command-and-control policy could increase costs ten times compared to other approaches to achieve the same amount of GHG reductions. Regulatory mandates on particular solutions (e.g., Renewable Portfolio Standards) increase demand for certain products and then lead to higher prices for consumers and a subsidy for producers.

Command-and-control regulations could also have many negative economic impacts on sensitive sectors such as the agricultural industry. The command-and-control program for GHG emissions is proposed as not suitable for agriculture as the industry has limited chances to offset the costs of the regulations by passing on price increases (EPA 2008). According to the American Farm Bureau Federation, farmers and ranchers would need to pay US$175 per dairy cow, US$87.50 per beef cow and US$21.87 per hog if GHGs were regulated under the Clean Air Act (Grondine & Harke 2009). In addition, some well-intentioned regulations turned out to be failures. EU legislation requiring that 5% of petrol and diesel consist of biofuels by 2010 (and 10% by 2020) combined with huge subsidies for first-generation biofuels in the EU and the US actually led to an increase in carbon emissions and food prices and also accelerated tropical deforestation (FitzRoy & Papyrakis 2010).

In summary, command-and-control regulations have played a significant role in improving the environment, particularly at the early stage of environmental regulation. Some of the regulations, such as energy efficiency standards, are effective. However, studies show that command-and-control regulations are far less cost effective than other economic instruments and negative economic impacts could arise in some sensitive sectors. Therefore, mitigating carbon emissions by the command-and-control instrument does not seem to be an ideal policy option.

2.3 Subsidies

2.3.1 The case for subsidies

Subsidies are bonuses or payment for doing something (Daly & Farley 2004). In the early 20th century, economist Arthur Pigou proposed internalizing environmental externalities by paying a subsidy to firms for reducing pollution, in which the subsidy equals the marginal benefit to society of abating pollution (Pigou 1952).

This is called a Pigovian subsidy (Daly & Farley 2004). A Pigovian subsidy implies that polluters have the right to pollute and society must pay them not to (Farley 2004) and so does not fulfill the polluter pays principle (Sterner 2003). It is a 'carrot' in the view of political economists (Bemelmans-Videc et al. 2003; United Nations Environment Programme 2008). Therefore, as a financial aid, subsidy is generally used under certain conditions. It is limited to well-defined transitional periods, or used to avoid creating significant distortions in international trade and investment, or employed to assist polluters in bearing the costs of pollution control in those parts of the economy where otherwise severe difficulties would occur (OECD 1997).

There are many forms of subsidies, from direct grants and tax exemptions to indirect payments in support of certain activities, such as financing technology research and providing public goods (Pershing & Mackenzie 2004; Sterner 2003). An emission reduction subsidy acts as a reward for reducing emissions. A public authority would pay an entity a specific amount per ton of emissions for every ton of emissions it reduces (Bashmakov & Jepma 2001; Field & Field 2006). Such a subsidy may encourage polluters to implement measures that are less costly than the subsidy to reduce emissions (Bashmakov & Jepma 2001). An energy subsidy is one of the most widely used subsidies. It is commonly defined as a payment by a government to energy producers or consumers for producing or using a certain type of energy (United Nations Environment Programme 2008).

Various types of subsidies may have different impacts. Fossil fuel-based subsidies promote the production and the use of fossil fuels, which inevitably boosts carbon emissions, while subsidizing the use of renewable energy and energy-efficient technologies may help to reduce emissions (United Nations Environment Programme 2008). Although an emission reduction subsidy would encourage each individual polluter to install abatement equipment to reduce emissions, total emissions may actually increase as the subsidy attracts more new firms to join the industry, thereby not guaranteeing a particular level of emissions (Bashmakov & Jepma 2001; Field & Field 2006; Xie 1995).

Meanwhile, subsidies are a drain on public revenue (Gunningham et al. 1998; Pershing & Mackenzie 2004). Especially for developing countries, they are expensive instruments as the opportunity cost of public funds is high (Sterner 2003).

Subsidies without time restriction can become locked-in and be difficult to remove (Nielson 2010). Some subsidies may cut down the marginal costs of firms, resulting in excess output and emissions (Nielson 2010). In addition, subsidies may encourage some firms' 'strategic behaviour', meaning that firms participate in certain activities only in order to gain the subsidy (Nielson 2010).

2.3.2 The practice of subsidies

In practice, a large number of subsidies are used for environmental policy purposes, such as promoting the diffusion of environmentally friendly products (e.g., residential insulation), rewarding environmentally friendly behaviour (e.g., compliance with environmental regulation), financing environmental infrastructure investments (e.g., renewable energy) and encouraging research and development (R&D). A typical example is the subsidy for the Mandatory Renewable Energy Target, which requires an increasing proportion use of renewable energy (Nielson 2010). By adopting such subsidies in Europe and Australia, the usage of renewable sources has been increased successfully, coupled with a reduction in emissions (Nielson 2010).

Energy subsidies, most of which flow to fossil fuels, are widespread due to the rationale of supporting economic growth (Moor 2001). According to IEA research, the amount of energy subsidies was about US$220 billion in the twenty largest non-OECD countries in 2005, of which fossil fuels-based subsidies accounted for around US$170 billion (United Nations Environment Programme 2008). Assuming other non-OECD countries had the same subsidy on each unit of energy consumption and the consumption subsidies were small in the OECD countries, worldwide energy subsidies are estimated at around US$300 billion per year, which accounts for 0.7% of world GDP (United Nations Environment Programme 2008). Research carried out by the National Academies of Sciences estimates that the US government has subsidized the energy industry by US$644 billion (in 2003 dollars) since 1950, most of which is in the form of tax breaks (43.7%) and R&D (18.7%) (Bezdek & Wendling 2006). Around half of the subsidies (US$302 billion) have gone to the oil industry.

Although fossil fuels still receive most of the energy subsidies, subsidies for clean energy technology have been growing steadily in recent years (United Nations Environment Programme 2008). Stern (2007) indicates that there are around US$26 billion in subsidies per year supporting the worldwide development of low-carbon energy sources, of which subsidies to renewable sources of electricity and existing nuclear power account for US$10 billion and about US$16 billion respectively. Moreover, biofuels also receive around US$6.4 billion (assuming global production of 40 billion litres) (Stern 2007). The National Academies of Sciences estimates that the US's renewable energies, including hydropower and geothermal, have received a total of US$111 billion since 1950 (Bezdek & Wendling 2006). According to a study by the Global Subsidies Initiative of the International Institute for Sustainable Development (2007), almost US$11 billion subsidies were spent on biofuels by only OECD countries in 2006.

Since some subsidies promote environmentally destructive behaviors (e.g., fossil fuels-based subsidies contribute to increases in carbon emissions and climate change), reform or removal of these kinds of environmentally harmful subsidies have started (OECD 2001; Sterner 2003; United Nations Environment Programme 2008). Angola cut its gasoline and diesel subsidies in September 2010 (IEA 2011). The German federal and state governments, the unions and Ruhrkohle AG agreed in 2007 to end coal-mining subsidies in Germany by 2018, which have been in existence for more than half a century (United Nations Environment Programme 2008). In September 2009 the leaders of the Group of Twenty countries agreed on removing damaging fossil-fuel subsidies in the medium term (The Global Subsidies Initiative 2010). Egypt also planned to eliminate energy subsidies to all industries by the end of 2011 (IEA 2011).

2.3.3 Empirical studies of subsidies

Various empirical studies confirm that subsidies to fossil-fuel consumption lead to larger GHG emissions and high economic cost (United Nations Environment Programme 2008). Kammen & Pacca (2004) estimate that the energy industry subsidy structure has contributed 1–7% of the total US carbon emissions. A study by

IEA (1999) indicates that US$257 billion per year is lost in only the eight largest non-OECD countries[5] as a result of consumer energy subsidies.

A series of studies have simulated the effects of removing fossil-fuel or other harmful energy subsidies. One study estimates that subsidy reform could achieve 8% CO_2 emissions reductions by 2035 (Dernbach & Koplow 2001). Research by the OECD reveals that the removal of all the subsidies around the world, used for lowering the price of fuels in industry and power sector, would reduce global CO_2 emissions by more than 6% and increase income by 0.1% by 2020 (United Nations Environment Programme 2008). According to a study by IEA (1999), primary energy use would be reduced by 13%, CO_2 emissions would be lowered by 16%, GDP would increase by almost 1% on average and annual economic growth rate would rise by 0.73% as a whole if the energy consumption subsidies were removed in the eight largest non-OECD countries. Removing energy subsidies can not only save energy and reduce GHGs, but also increase overall economic efficiency (Toman 2003).

The social implication of reforming fossil-fuel subsidies has also been explored. Burniaux et al. (1992) reveal that the removal of energy consumer subsidies in non-OECD countries would increase global welfare by US$35 billion and the real income for the whole world by 0.7% annually. However, the distribution of this welfare would be uneven. They further find that GDP and real income would decline greatly in some non-OECD countries even if the aggregate GDP and real income effect were positive for the overall global and non-OECD countries (Burniaux et al. 2009). Moor (2001) proposes that the distributive effects of fossil-fuel subsidy reforms are quite modest. The income decreases slightly more than 3% at maximum but the low-income urban households that depend on commercial fuels are affected most.

In summary, the economic, environmental and social effects of subsidies are complex and depend on the precise nature of the subsidy and energy source. However, it is clear that the removal of harmful energy subsidies would reduce governments' budget burdens, increase energy savings and lead to emission reductions, economic growth and economic efficiency, even though it may have a

[5] The eight largest non-OECD countries mentioned by IEA (1999) are China, The Russian Federation, India, Indonesia, Iran, South Africa, Venezuela and Kazakhstan.

negative distributional effect. In practice, subsidizing alternatives (clean or less carbon-intensive energy sources) and removing environment damaging subsidies (e.g., for fossil fuels) are common in mitigating carbon emissions, while the use of direct emissions reduction subsidies appears to be rare. However, no country is relying on pro-reduction subsidies to achieve its carbon reductions target. This may be due to the nature of subsidies (i.e., against polluter pay principle), the uncertainty of emissions levels and the drain on public revenue. Moreover, some pro-reduction subsidies are introduced for purposes other than reducing emissions. For example, subsidies to nuclear power in several countries are explained by the need to reduce independence on imported energy (United Nations Environment Programme 2008). In addition, a problem with subsidies is the notion of ‘picking winners’. It might be that a number of clean energy technologies could be subsidized, with no certainty of which ones will be widely adopted. Therefore, it seems that subsidizing the alternatives along with removing the harmful subsidies cannot be used as a major policy for achieving the carbon reduction target. Rather, it is more suitable to act as a supplementary instrument in supporting the main policy for mitigating carbon emissions.

2.4 Pollution Taxes

2.4.1 The case for a carbon tax

The concept of a carbon tax is based on the polluter pays principle (Sandu 2007). A carbon tax is one kind of Pigovian taxes that aims for convergence between social and private cost by imposing a tax supposedly equal to the marginal social cost (Helm 2005; Tomás et al. 2010). It mitigates carbon emissions by reducing energy consumption and changing fuel choice through a price mechanism (Zhang & Baranzini 2004). A carbon tax can be implemented on the basis of the carbon content of fuels, requiring the payment of a fixed fee for every ton of CO_2 emitted (Hoeller & Wallin 1991). It is widely supported by economists for reducing GHG emissions (Shrum 2007).

A carbon tax can raise revenue for a government and stimulate energy savings, innovation and investment in clean technology (Ekins & Barker 2002). A carbon tax is considered as the easiest policy to implement and monitor through making use of existing tax structures (Ekins & Barker 2002; Owen 1992). With a carbon tax the cost of reducing emissions is predictable (Nielson 2010). It is also argued that environmental taxes may result in a ‘double dividend’, which means an improvement in both environment and economic efficiency at the same time (Pearce 1991). However, due to uncertainty about the equity of Pigovian taxes and the appropriate damage cost, the level at which the tax is set to achieve the optimal outcomes is not known in advance (Nielson 2010; Pearce & Turner 1990). In addition, a carbon tax is likely to be politically unpopular (Nielson 2010). Businesses are unsatisfied with it as they have to transfer revenue to the government, while environmental groups oppose it as it fails to guarantee a particular level of emissions (Pizer 2002). It is also argued that carbon taxes have regressive impacts on the international competiveness of economies and the distribution of income (Zhang & Baranzini 2004).

2.4.2 Carbon taxes in practice

In response to emissions reduction commitments under the UNFCC, some European countries have implemented either a carbon tax or an energy tax based partly on carbon content (Bashmakov & Jepma 2001). These include Finland (1990), Sweden and Norway (1991), Denmark and Netherlands (1992), Austria (1995), Slovenia (1998), Italy, Germany and Luxembourg (1999), the United Kingdom (UK; 2001), Belgium (2003), and Switzerland (2008) (Baranzini et al. 2000; Ekins & Barker 2002; IEA 2010b; Martini 2009; Scrimgeour et al. 2005). The Republic of Ireland introduced a carbon tax in 2010 (Ireland Business 2009). However, none of these countries has been able to introduce a uniform carbon tax for fuels in all sectors and various forms of exemptions exist in most cases. The EU has attempted to introduce a unitary carbon tax for all EU member states several times since the early 1990s, but it has failed due to industrial lobbying (Pearce 2005). In 2010 the European Commission considered implementing a pan-European minimum tax on pollution permits purchased under the EU ETS (Kanter 2010). As the tax was based on carbon content rather than volume, fuels with high carbon concentration would carry high prices.

In addition to the abundant carbon tax experiences in Europe, some countries or regions in other continents have used carbon taxes even though the coverage is relatively limited. These include South Africa, Costa Rico, India, the US and Canada

(City of Boulder 2011; Meyer 2010; Ministry of Environment and Forests Government of India 2010; The Canada 2008; Xinhua 2010). The carbon tax in South Africa only covers new motor vehicles and the tax in India is limited to coal products (2010). Although a federal carbon tax has not been introduced in the US or Canada, carbon taxes have been implemented in some American states and Canadian provinces. In 2006 Boulder in Colorado introduced the first municipality-level carbon tax in the US (City of Boulder 2011). The carbon tax in Montgomery County, Maryland is said to be the US's first county-level carbon tax (Dernoga 2010). Table 2.1 summarises information about the energy or carbon taxes which have been implemented around the world.

Some countries or regions such as Australia and Taiwan are currently introducing or considering carbon taxes. On 8 November 2011 Australia passed the Clean Energy Bill to introduce a carbon tax of $23/tC, which would increase by 2.5% annually, on the 500 largest polluters from 1 July 2012 for three to five years, followed by a move to an emissions trading system (Gillard 2011; Thompson 2011). Taiwan's plan to adopt a carbon tax in 2011 met opposition from the public but the policy is still under consideration (Patel 2011).

Carbon or energy taxes proposals in some countries have been delayed or failed (e.g., Japan, South Korea, New Zealand and France). Japanese authorities proposed an environmental tax in 2005, but it was delayed due to major opposition from the Petroleum Association of Japan, other industries and consumers (Maeda 2009). South Korea announced plans to replace the transportation tax by a carbon tax in 2010 (Hyun-cheol 2008), but it failed because of strong opposition from the Korean Chamber of Commerce and Industry (Yoo-chul 2010). New Zealand's proposed carbon tax in 2005 was scheduled to take effect from April 2007, but it was abandoned in December 2005 (Hodgson 2005; New Zealand Press Association 2005). A new carbon tax in France was intended to come into effect on 1 January 2010, but it was blocked by the French Constitutional Council on the day before it became effective (Kanter 2009).

Table 2.1 Worldwide experience in carbon tax and energy tax (by year)

Region /Country	Tax Program	Implementation year	Main features
Finland	CO_2 tax	1990	The first country in the 1990s to introduce a CO_2 tax. Currently, energy-intensive firms are partially excluded.
Norway	CO_2 tax	1991	Applies to fossil fuels and the production of oil and gas offshore. Among the highest carbon taxes in the OECD. According to IEA 2005 Review of Norway, Norway's CO_2 tax covers about 64% of Norwegian CO_2 emissions and 52% of total GHG emissions.
Sweden	CO_2 tax	1991	Based on the use of oil, coal, natural gas, liquefied petroleum gas, petrol, and aviation fuel used in domestic travel. In 2007 the tax was SEK 930 (€101) per ton of CO_2.
Denmark	CO_2 tax	1992	The CO_2 tax applies to all energy users, including the industrial sector. But the industrial companies can be taxed differently according to two principles: the process the energy is used for, and whether or not the company has entered into a voluntary agreement to apply energy efficiency measures.
Netherlands	Carbon/ energy tax	1992	Assessed partly on carbon content and partly on energy content.
UK	Fuel duty escalator (FDE)	1993-2000	The tax was on retail petroleum products and was explicitly designed to reduce CO_2 emissions in the transport sector. Since carbon is in fixed ratio to the quantity of fuel, the FDE roughly approximated a carbon tax. The fuel price escalator was set at an annual increase of 3% ahead of inflation, later rising to 5%.
	Climate change levy	2001	Adds about 15% to the cost of electricity. The revenues are recycled by reducing the National Insurance contributions of those who pay the levy. Part of the revenue is also used to assist businesses adopt energy efficiency.
Austria	Energy tax	1995	Started from oil products and covered gas and electricity in 1996. The tax does not consider the carbon content of the energy products.
Costa Rica	Carbon tax	1997	A portion of the funds generated by the tax go to the 'Payment for Environmental Services' program which gives incentives to property owners to practice sustainable development and forest conservation.

Region /Country	Tax Program	Implementation year	Main features
Slovenia	Carbon tax	1998, 2005	The carbon tax was first introduced in 1998 and it was replaced with a new carbon tax in May 2005. It covers only relatively smaller installations as the energy intensive installations, which are part of the EU ETS, are exempted from the carbon tax payment. It has different taxation levels for different fuels.
Italy	Carbon tax	1999	The tax is on the consumption of energy products. The excises had to be raised every year for the next five years in order to meet a target level in 2005.
Germany	Ecological tax	1999	The tax is on heating fuel, petrol, natural gas and electricity. The tax was slowly increased from 2000 to 2003 and now remains at 2003 levels.
Luxembourg	Energy tax	1999	The businesses that undergo voluntary energy or environmental audits and demonstrate other efforts to increase efficiency are exempted from the tax.
Belgium	Energy tax	2003	On fuels and electricity (increase for liquid petroleum products, decrease for natural gas for households).
Boulder, Colorado, US	Carbon tax	Nov. 2006-31 Mar. 2013	The first municipal carbon tax. It is a tax on electricity consumption (utility bills) with deductions for using electricity from renewable sources.
Alberta, Canada	Carbon tax	1 July 2007	Only covers the companies that emit more than 100 000 t of GHG annually.
Quebec, Canada	Carbon tax	1 Oct. 2007	The first province in Canada to introduce a carbon tax. The tax is imposed on energy producers. The revenue is used for energy-efficiency programs, including public transit.
Switzerland	CO_2 tax	Jan. 2008	The tax is on all fossil fuels unless they are used for energy. Companies are allowed to exempt themselves from the tax by participating in a Swiss cap-and-trade ETS. The tax is revenue neutral.
California, US	Carbon tax	May 2008	A carbon tax on businesses of 4.4 cents/t of CO_2.
British Columbia, Canada	Carbon tax	1 July 2008	The tax will increase each year until 2012, reaching a final price of $30/t (7.2 c/L at the pump). The legislation will keep the pending carbon tax revenue neutral by reducing corporate and income taxes at an equivalent rate.
Republic of Ireland	Carbon tax	2010	The carbon tax is levied at €15/t of CO_2 emissions. The carbon tax applies to kerosene, marked gas oil, liquid petroleum gas, fuel oil and natural gas. The natural gas carbon tax does not apply to electricity because the cost of electricity is already included in pricing under the Single Electricity Market.

Region /Country	Tax Program	Implementation year	Main features
Montgomery County, Maryland, US	Carbon tax	May 2010	It is the first county-level carbon tax in the US. Any stationary source emitting more than a million tons of CO_2 during a calendar year need to pay US$5/t of CO_2 emissions.
India	Carbon tax	1 July 2010	A nationwide carbon tax of 50 rupees/t (US$1/t) of coal both produced and imported into India.
South Africa	CO_2 tax	1 Sep. 2010	The tax is implemented on new motor vehicles, but limited to new passenger vehicles and new light commercial vehicles (double cabs and small bakkies). It applies at the time of sale and relates to the amount of CO_2 emitted by the vehicles. Based on the certified CO_2 emissions at 75 rands/g/km (US$10.26/g/km) for each g/km above 120 g/km.

Sources: Baranzini et al. (2000), CBC News (2008), City of Boulder (2011), Dergona (2010), Ekins & Barker (2002), Kranjcevic (2007), Lauber (2002), Martini (2009), Ministry of Environment and Forests Government of India (2010), ODYSSEE (2011), OECD (1997), Parliament of Australia (2011), Pearson (2010), Scrimgeour et al. (2005), The Canada (2008), Xinhua (2010) and Zito (2008).

2.4.3 Impacts of a carbon tax

The carbon tax impacts on emissions reductions by making energy savings initiatives more viable, by promoting technological development of energy-saving products, and by reducing consumption (Andersen et al. 2000). The literature offers a range of ex ante and empirical studies of the extent to which a carbon tax can reduce emissions, but the results vary among different studies. In 1997 the Swedish Ministry of Environment projected that 20–25% CO_2 reductions would be achieved in 2000 on the basis of 1990 levels by the Swedish CO_2 tax (Johansson 2000). But the Swedish Environmental Protection Agency (1997) evaluated the Swedish CO_2 tax and found that the emissions in 1994 were only about 5 Mt lower than the business-as-usual scenario. The Danish Environmental Protection Agency (1999) estimates that 1.6% CO_2 emissions would be reduced by the Danish CO_2 tax. By doing a counterfactual analysis of the Norwegian CO_2 tax, Larsen & Nesbakken (1997) find that it has contributed 3–4% CO_2 reductions in Norway during the period from 1991 to 1993. Another empirical study of the Norwegian carbon tax shows that the outcomes from this policy are small, involving only 2% emission reductions (Bruvoll & Larsen 2004). A summary of various studies in the 1990s of the emissions reduction effect of Norwegian CO_2 tax has estimated a range from 2.5% to 11% compared with the business-as-usual scenarios (Prasad 2008).

The macroeconomic effects of carbon taxes have been extensively modelled, with dynamic optimisation, CGE and marcroeconomic simulation being the three main approaches (Ekins & Barker 2002). The model results are influenced by the models used and assumptions concerning the recycling of tax revenues (Repetto & Austin 1997). By doing a comparative study of the results from US models, Repetto and Austin (1997) estimate that a 30% reduction in US baseline emissions by 2020 would reduce GDP by 3% in the worst case, and increase GDP by 2.5% in the best case. The total of 5.5% cost difference in GDP can be attributed to the model approaches adopted and the recycling (of the revenue) assumptions. For carbon taxes with lump-sum recycling, Ekins & Barker (2002) summarize a number of individual country studies and find that the general results are that 15–25% CO_2 emissions reductions by 2010 would lead to a GDP loss of 0.1–1.2%. However, a series of studies confirm the findings of Repetto & Austin (1997) that GDP could rise above the baseline with a carbon tax under the assumption that the tax revenues are used to reduce employment taxes, a tax swith (Barker 1999; Barker & Köhler 1998; Garbaccio et al. 1999, 2000; Houghton et al. 1996; Jorgenson & Wilcoxen 1993; McDougall & Dixon 1996; Zhang 1998c).

This economic effect is the ‘double dividend’, which was first set out by Pearce (1991). Jorgenson and Wilcoxen (1993) find that a 1.7% GDP loss under lump-sum redistribution is converted to a 0.69% loss when the carbon tax is used to reduce labour taxes, and there would be a 1.1% gain if the carbon tax is used to reduce capital taxes. By employing a CGE model in China, Zhang (1996) finds that welfare may be improved if carbon taxes are used to reduce some other taxes. Garbaccio et al. (1999, 2000) with another dynamic CGE model for China, but using carbon tax revenues to reduce all other taxes, suggest that GDP would increase in the long run. But some studies argue that the use of revenues to reduce employment taxes does not generally appear to increase the GDP (Goulder 1995; Jorgenson et al. 1995; Shackleton et al. 1996). The existence of the double dividend in practice is still under debate.

The distributional effects of a carbon tax are complex, including both intended and unintended impacts. The different impacts of a carbon tax on the competitiveness of different sectors is an example of intended effect, since the relatively carbon-intensive sectors experience a higher tax burden (Ekins & Barker 2002). Pezzey (1992) simulates the introduction of a carbon tax of US$100/t in the UK and finds that only the four most carbon intensive sectors (iron and steel, chemicals, non-ferrous metals and non-metallic minerals) experience cost increases when the revenues are redistributed to the sectors relative to their output. By using data from 21 OECD countries and nine sample energy-intensive industries, Zhao (2011) finds that a carbon tax has a negative impact on the international competitiveness of energy-intensive countries. However, there can be unintended effects on different regions or income groups (Ekins & Barker 2002). In most instances, firms can pass the costs of a carbon price to consumers by increasing product prices (Neuhoff 2008). Low-income families may suffer more as they spend a larger fraction of their available income on energy-intensive goods than high-income people do (Neuhoff 2008). Smith (1992) reveals that fuel expenditures relative to total expenditures for the lowest income quartile are 1.2% higher than for the highest quartile in Italy, 1.9% in Spain, 2.7% in Netherlands, 3.4% in France, 3.5% in Germany and 5.8% in Ireland. Results from empirical studies show that carbon taxes are generally regressive, but less than first expected (Barde 1997; OECD 1997). The regressive distributive impacts of a carbon tax could be relieved by tax exemptions or household transfers (Bashmakov & Jepma 2001).

The impact of carbon taxes has been examined from three main aspects: environmental, economic and distributional effects. Overall, a carbon tax would likely to reduce emissions but it may have negative macroeconomic effects and regressive distributional effects. However, if the revenues were used to offset other taxes, there is the possibility of the double dividend effect. In practice, a carbon tax is usually accompanied by tax exemptions or subsidies to support the energy-intensive sectors and low-income groups. Therefore, the negative impacts of a carbon tax may be less than expected. The review of the experience of carbon taxes in this section suggests that a carbon tax appears to be a desirable policy instrument that can be used to mitigate carbon emissions, but it is not ideal for achieving particular targets, which is where emissions trading has an advantage.

2.5 Emissions trading

2.5.1 The case for emissions trading

The idea of emissions trading, introduced by Dales (1968) and later formalized by Montgomery (1972), was based on the Coase Therorem. Externality theory, economic transaction cost theory and property theory for environmental capacity resources are the three major theories behind emissions trading (Jutila 2008). It is argued that much environmental depletion and pollution is caused by inadequately defined and insecure property rights (Gunningham et al. 1998). In response to this problem, the Coase Theorem suggests that 'if there were (a) no wealth effects on demand, (b) no transaction costs and (c) rights to pollute or control pollution, the allocative solution would be invariant and optimal, regardless of the initial assignment of rights' (Frech 1973, p. 254). By creating property rights for a public good (Sterner 2003), which in this case is the atmosphere, 'emission trading schemes assign private property rights to emitters and according to the Coase Theorem this should be sufficient to lead to an efficient outcome' (Betz 2006, p. 2).

By using a model of a perfect market with pollution allowances (permits), Montgomery (1972) finds that a cost minimum equilibrium exists when an environmental target is given to companies. Therefore, according to the supply-and-demand theory in microeconomics, the permit price should increase under a cap-and-trade system in the long term, which provides greater incentives for business to make efficient investment decisions (Egenhofer 2007). According to Montgomery (1972), an ETS with this price mechanism would be an efficient instrument for achieving environmental targets.

Besides providing more certainty about emission levels, it can be linked to other countries' carbon reduction programs (Stavins 2008). Emissions trading allows entities the flexibility to take the most cost-effective action to meet limits and it could improve long-term predictability, provide certainty and minimize the distortions to competition in the market (Egenhofer 2007; Leung et al. 2009; Tomás et al. 2010; Zhang 1998a). Moreover, it may provide growth for new business and trading opportunities (Leung et al. 2009). Emissions trading has several disadvantages, including high start-up costs, long set-up time and political barriers

(Leung et al. 2009). In addition, cap-and-trade emissions trading schemes rely on markets, which could be severely affected by unforeseen events (Nielson 2010).

2.5.2 Emissions trading practice

Early emission trading practice took place in a relatively small number of countries, predominantly in the US, before becoming popular throughout the world (OECD 2002). To date, there have been numerous applications for the issuing of tradable permits. A survey by the OECD (1999) reported nine applications in air-pollution control, seventy-five in fisheries, eight for water and five for land use by 1999. More recent developments include tradable renewable energy certificates (green certificates), tradable energy efficiency improvement certificates (white certificates) and trading in waste, transport emissions and GHGs (OECD 2002).

The US Acid Rain Program was introduced in 1990 following the passage of the 1990 US Clean Air Act to reduce SO_2 from electric power plants (Kinsman 2002), which is the best-known and most successful experience with emission trading (Ellerman et al. 2003; Kinsman 2002). The reasons for this success summarized by Kinsman (2002) include the use of an attainable cap with reasonable deadlines, two phases of reduction, flexibility for sources to achieve compliance, accurate measurement of emission and severe penalties for non-compliance.

The EU ETS, which has followed the practices pioneered by the US Acid Rain Program, was introduced in 2005 and is by far the largest carbon trading system in the world. It sets mandatory caps on CO_2 emissions for the 27 member countries of the EU, representing 99% of the volume of allowances traded globally in 2006 (King 2008a). The EU experience with emissions trading suggests that the rules for a cap-and-trade system should be clear and easily enforced, otherwise market function will suffer and transaction costs will increase (King 2008a).

Emissions trading began to be discussed and piloted in China early in the 1980s, but it was primarily conceptual with few applications because of legal and regulatory constraints. It was first used to control sewage in Jiangsu Province and Shanghai Municipality in 1987 (Lin & Feng 2008; Zhou 2009). In 1994 the Chinese State Environmental Protection Administration (SEPA) conducted policy experiments in air pollutant emission trading in six cities[6] (Yang et al. 2003). Then in 2001 Taiyuan city introduced a SO_2 trading program with financial assistance from the Asian Development Bank (ADB) and technical assistance from the US Resource for the Future (RFF) and Chinese Academy for Environmental Planning (CAEP). The SO_2 emission trading program was extended to seven provinces or cities[7] in 2002.

Carbon emissions trading programs have been introduced in several countries, including Canada, the US, Japan, New Zealand, the Netherlands, Switzerland and the UK (Climate Change Information New Zealand 2011; Leung et al. 2009). However, most of these programs are not mandatory and/or are not implemented at the national level, or are not cap-and-trade programs. Carbon trading systems have also been implemented at a local government and company level, including the New South Wales Greenhouse Gas Abatement Scheme in Australia and CO_2 trading in the state of Massachusetts in the US, and in BP, Royal Dutch Shell and the Chicago Climate Exchange (Philibert & Reinaud 2004). A summary of the worldwide experiences in air pollutants emissions trading is presented in Table 2.3.

Table 2.3 Worldwide experiences in air pollutants emissions trading (by year)

Region/ Country	Program	Trading pollutant	Implementation year	Main features
US	Southern California's RECLAIM Program	SO_2 and NO_X	1994	Include over 40 companies and industrial facilities in the Los Angeles area.
	Acid Rain Program	SO_2	1995 (phase 1) 2000 (phase 2)	A cap-and-trade system for SO_2; Mainly among electric utilities; Two-phase.
	Chicago Climate Exchange	CO_2, CH_4,N_2O, HFC,PFC, SF_6	2002 2005	First voluntary carbon trading scheme implemented in the US; Companies with emissions over 250 000 t e-CO_2, 33 entities; Participants can choose reducing emissions directly, purchasing permits from other participants or getting credits from agricultural or other offset projects to meet the commitment.

[6] Baotou, Kaiyuan, Liuzhou, Taiyuan, Pingdingshan and Guiyang.
[7] The seven provinces or cities are Tianjin, Jiangsu, Zhejiang, Shanghai, Shanxi, Henan and Guangxi.

Region/ Country	Program	Trading pollutant	Implementation year	Main features
US	Regional Greenhouse Gas Initiative (RGGI)	GHGs	2009	A mandatory cap-and-trade scheme covering 209 fossil fuel electricity generators across ten northeastern states in the US.
Canada	Pilot Emissions Reduction Trading (PERT) Project	GHGs and other pollutants	1996	A think tank was established and has coordinated pilot trades between American and Canadian companies; Revealed that a project-based GHGs emission reducing trading is feasible.
EU	Eurelectric's Pilot Project	CO_2	2000	Involved 40 major European companies in various sectors;
	EU ETS	CO_2	2005 (phase 1) 2008 (phase 2)	The first and largest mandatory cap-and-trade scheme for CO_2 in the world; It covers all 27 EU members states and three non-members (Iceland, Liechtenstein and Norway); Targets across four broad sectors: iron and steel, minerals, energy, and pulp and paper.
BP		CO_2, CH_4	2000	Participation is voluntary for BP, but mandatory for the operating units.
Shell		CO_2, CH_4	2000-2002	Voluntary basis; 6 business units in Annex I countries.
Denmark	CO_2 ETS	CO_2	2001	Targeted at CO_2 emissions from power plants that were not covered by CO_2 taxes; The main focus for this scheme was to transit into the EU ETS.
UK	Greenhouse Gas Emissions Trading Program	CO_2	2001	Voluntary basis; Covering all UK-based entities not covered by other agreements or directives; Reduction target and financial incentive are determined through an action process.
	CRC Energy Efficiency Scheme	CO_2	2010	A mandatory cap-and-trade scheme applying to large non energy-intensive organizations in the public and private sectors that are not covered by the EU ETS; The organizations are responsible for about 10% of the UK's emissions.

Region/ Country	Program	Trading pollutant	Implementation year	Main features
The Netherlands	Emission Reduction Units Procurement Tender (ERU-PT)	CO_2	2001	The Dutch Government provides funds for acquisition of ERUs from eastern European countries; A single buyer (the Dutch Government) purchasing ERU from multiple sellers in other countries.
China	4-3-1 Emissions Trading Project	SO_2	2002	Involve four provinces, three cities and one enterprise.
New South Wales, Australia	Greenhouse Gas Abatement Scheme	CO_2	2003	For electricity retailers and other parties; Participants may purchase or use abatement certificates to offset emission; May also reduce emission to generate certificates.
Japan	Domestic ETS	CO_2	2008	Voluntary domestic ETS; Cover large-scale emissions from industry, industrial process and energy conversion sectors; A policy mix consisting of an ETS and a tax on emissions.
Switzerland	Swiss ETS	CO_2	2008	A voluntary scheme run in conjunction with an exemption from the mandatory CO_2 taxes; Plan to link to the EU ETS.
New Zealand	New Zealand ETS	GHGs	2008	A national all-sectors all GHGs all-free allocation uncapped ETS; Individual sectors of the economy have different 'entry day'.

Data source: adapted from Haites et al. (2001), Leung et al. (2009) and Climate Change Information New Zealand (2011).

More countries are developing carbon emissions trading schemes. For example, Korea plans to begin a scheme in 2015 (Climate Change Information New Zealand 2011). However, not all the attempts to establish an emissions trading approach have succeeded: early proposals in Norway (OECD 1999; Tietenberg 2003), Germany (Scharer 1999), Poland (OECD 1999; Tietenberg 2003; Zylicz 1999) and the UK (OECD 1999; Sorrell 1999; Tietenberg 2003) failed. The Australian Government's 'White Paper' in December 2008 outlined a Carbon Pollution Reduction Scheme (CPRS) that would be implemented in July 2010, but this plan was rejected twice by the Senate. It was subsequently delayed and then revamped to be in the Clean

Energy Act in November 2011 (Commonwealth of Australia 2008; Kelly 2010; Thompson 2011). The RECLAIM program for mitigating nitric oxide (NO_X) and SO_2 emissions among stationary sources in America was another failure. Soleille (2006) identified lessons to be learnt from this program: it should take time to prepare; the market is very important; the participation should be enlarged; the penalty for non-compliance should be automatic; and the banking of allowances should be allowed. Another obvious lesson from this program is that trading should involve low transaction costs (Stavins 1997).

2.5.3 Impacts of emissions trading

The impacts of emissions trading schemes so far have been analyzed from different viewpoints. Emission reductions, emission cost, innovation and investment in clean technology and leakage are the four major perspectives. Some researchers have investigated the actual performance of the emissions trading systems, while many can only simulate the possible outcomes due to the limited number of practices or data unavailability.

The first set of research examines the emission reductions attributed to the emission trading programs. About 15 months after the introduction of the emissions trading program in Sweden, a survey conducted in the emission trading sectors shows that the EU ETS does make participants take action and/or plan to reduce emissions (Sandoff & Schaad 2009). However, the emissions data of EU ETS during 2005–07 indicates that CO_2 emission reductions are not noticeable (Jutila 2008). One explanation is that the caps are not low enough to push the companies to take emission control actions in the short term (Jutila 2008). Statistics from the US Environmental Protection Agency (EPA) show that the US Acid Rain Program was estimated to have achieved about 40% emission reductions of the 1980 levels by 2001 and the reductions would increase to 50% by 2010 (Kinsman 2002). Hidalgo et al. (2005) forecast that the global direct emissions from the iron and steel sector will reduce by 15% in 2030 in the context of CO_2 emission trading.

The second research area is concerned with the cost effectiveness of emissions trading. Historic examples have revealed that a cap-and-trade ETS is by far the most cost-effective instrument for regulating emissions (Agricultural Carbon Market

Working Group 2010). Compared with command-and-control regulations for SO_2, a cap-and-trade program is found to have achieved US$1 billion cost savings annually (Stavins 1998). A survey by Burtraw (2000) finds that the US Acid Rain Program contributed tremendous cost savings compared to the conventional approach and even compared to original forecasts, with the actual costs being just one-half to one-quarter of the initial projection. This achievement is also supported by the statistics from the US EPA (Kinsman 2002). By reviewing the empirical literature on US emission trading schemes, Gagelmann and Frondel (2005) conclude that an ETS is a low-cost strategy.

The third and most popular area of ETS studies assesses the impact of emission trading on innovation and investment in clean technologies. Using a duration model applied to a panel of refineries from 1971 to 1999, Kerr and Newell (2003) note that the tradable permits system used during the phasedown of lead in gasoline really resulted in more R&D and more efficient technology adoptions. From investigating the power sector in Finland, Laurikka and Koljonen (2006) find that a quantitative investment appraisal is affected greatly by the ETS through several variables such as output price. Peace and Juliani (2009) argue that the US future cap-and-trade program will provide a larger incentive for innovation in low-carbon technologies by placing a price on carbon emissions and creating a market. According to a survey carried out by the European Commission during June to September 2005, about half of the companies announced that their decisions to invest in clean technology could be attributed to the EU ETS at least half or more (European Commission et al. 2006). However, after reviewing the literature on previous emission trading systems in US, Gagelmann and Frondel (2005) expect only limited innovation effects from the EU ETS in the first years. By explaining the mechanism of EU ETS, Bleischwitz et al. (2007) also find the EU ETS has not yet provided incentives for long-term innovation dynamics such as the transition to a hydrogen economy.

In addition, other possible impacts such as price increases and leakages have been investigated. Sousa et al. (2005) develop a simulator to assess the impact of CO_2 emission trading on the Iberian electricity industry and discover that the electricity prices will rise when CO_2 constraints are in place. Koljonen and Savolainen (2004) arrive at the same conclusion by applying a stochastic electricity price model in the

Nordic area. Under the assumption that carbon prices are likely to increase, Bleischwitz et al. (2007) reveal that the EU ETS may make some energy intensive industries relocate their production to outside the EU. Hidalgo et al. (2005) also conclude that the emissions and production will leak from EU15[8] to the rest of the world, mainly China, when the EU15 emission trading is implemented. However, an empirical study of the US Acid Rain Program finds that the scheme has not resulted in a geographic shifting of emissions (Environmental Defense Fund 2009)

Theoretically, a successful ETS would result in a series of desirable outcomes such as reducing emissions, saving emission reduction costs, promoting innovation and increasing investment in clean technology, without inducing companies to relocate (named as the *Theoretical Emissions Trading Response Model* in this research). The above literature review shows that the emissions trading programs do have an impact on the companies' behaviours, which suggests that emissions trading could be an effective policy in reducing carbon emissions. However, our review also reveals some unintended consequences from the ETS, which suggests that the actual effect should be examined on a case-by-case basis. While many studies investigate the possible or actual impacts of emissions trading in developed countries, little attention has been given to the outcomes of the existing emissions trading practice in China. Whether an ideal outcome can be realized in China as suggested by the theory remains to be answered.

2.5.4 Emissions trading markets

The foremost foundation of emissions trading instruments is based on the idea of market efficiency, so the emissions trading market plays a significant role in evaluating the practice of an emissions trading program. Observations from the existing emissions trading markets of the US SO_2 program and the EU ETS provide preliminary insights for problems that might arise in other emissions trading markets.

The participants in the US SO_2 trading program have been provided with many compliance choices, including buying permits from the market, switching to low-sulphur energy sources, employing clean technology, increased use of non-sulphur

[8] Include Austria, Belgium, Luxembourg, Denmark, Spain, Finland, France, the UK, Greece, Ireland, Italy, Netherlands, Portugal, Germany and Sweden.

energy sources (nuclear, hydropower, wind and thermal energy etc.) or adopting energy conservation measures to reduce energy demand and emissions (Rico 1995). A public report published by the US EPA in 1993 showed that only 9% of companies, which had announced their compliance strategies during Phase 1 (1995–99) and Phase 11 (2000–10), would employ the permits trading strategy, while 63% of participants decided to take the fuel switching strategy (Rico 1995). Excluding transactions through the annual auction, slightly more than 2.3 million allowances had occurred involving 27 major trades (more than 10 000 permits) and only 12 firms had bought more than 5000 permits from other utilities by early 1995 (Burtraw 1996).

A number of studies and reviews explore the reasons why so few permit trades took place at the early stage of the US SO_2 trading program. One reason is because of the transaction costs involved (Stavins 1995). Another explanation points to the conflict between the existing standard regulation of electric utilities and the trading program (Bohi & Burtraw 1991). Furthermore, the limits of the earnings on capital gains but not capital losses expose the participants to a great risk in buying permits from the market (Burtraw 1996). Moreover, the evolution of regulatory policy is uncertain, which makes the firms cautious in participating in trading (Burtraw 1996). In addition, the permit costs are not covered until the permits are used, which imposes an interest burden on the firms (Burtraw 1996). Finally, negative public attitudes toward permits trade erodes the enthusiasm for trading (Burtraw 1996).

A web survey conducted by Sandoff & Schaad (2009) in 2006 on the 221 Swedish companies covered by the EU ETS shows that even the trading frequency between large companies was every low and only half of the respondents had engaged in trading until the survey time, about 15 months after the scheme started. Typically, most of the companies that engaged in trading only traded once a year. In addition, the majority of the companies used brokers to engage in trade while less than one in five trades happened directly at a CO_2 exchange[9]. All the findings from the survey indicate that very few companies were interested in the permit trading market. The infrequent trading can be explained by the companies' trading strategies to some

[9] Three methods are available for allowances trading in EU ETS: by brokers, by one of the official CO_2 exchanges or through bilateral agreements with companies covered by the EU ETS (Sandoff & Schaad 2009).

extent (Sandoff & Schaad 2009). Some companies adopt risk management strategies to avoid the price uncertainty of the emission market. For example, a cost averaging strategy enables companies to sell or buy permits spread over a long period with the intention that they can avoid buying large volumes at the high price or selling at the bottom of the market (Kruger 2005b; Sandoff & Schaad 2009). This has also been observed in the US SO_2 trading program (Kruger 2005b).

Another explanation for low frequency trading is that the companies predict that they have been already provided with enough permits during the first trading period (Sandoff & Schaad 2009). According to the experience from the US SO_2 trading program (Burtraw 1996), a possible reason for this phenomenon is that the participants rely on other measures to achieve permits balance rather than trading. These measures include reducing emissions by improving the equipment of the company, getting extra permits by investing in project-based mechanisms under the Kyoto Protocol and relocating permits between the branches located in different countries within the EU ETS (Sandoff & Schaad 2009). In that sense the cap acts more like a regulation than as part of the market mechanism.

The price of carbon emissions per tonne in the EU ETS trading market has experienced great fluctuation (MacKenzie 2007). The carbon price rose markedly from January 2005 to March 2006, peaking at €31/t. On 26 April the European carbon price fell 30%, and the carbon allowances were traded as low as €9 by mid-May 2006. In early 2007 one could buy the right to emit a tonne of CO_2 for as little as €1. The EU carbon market could be said to be a failure because too many permits had been distributed and the caps on emissions had not been set tightly enough, with supply greatly exceeding demand (FitzRoy & Papyrakis 2010; MacKenzie 2007). After this experience, the EU took the initiative to cut emission caps and push up the price of carbon permits (with plans but no firm commitments to auction permits in the future) (FitzRoy & Papyrakis 2010). This experience with the EU ETS indicates that the design and setting of the ETS is of great importance in fostering an efficient trading market.

2.5.5 Key elements of a well-designed emissions trading program

Many studies have expressed the same views on the key elements of designing emissions trading schemes (Muller & Mestelman 1998; Philibert & Reinaud 2004; Svendsen & Vesterdal 2003). These include targets, coverage of the scheme, allocation methods, banking and borrowing, linkage and the compliance system. However, difficulties arise in deciding the design features appropriate for a particular country (Hahn 2000).

Targets

When setting up a specific overall target, a country will have to consider whether other countries can accept the target and whether the economy can afford to achieve this target (Huang & Lee 2009). In addition, countries need to make the decision between absolute targets (expressed as total emissions in a specified period) and relative/rate-based targets (expressed as an emission rate per unit of output or input or activity) (Philibert & Reinaud 2004). It is argued that the relative target is more flexible and popular (Gielen et al. 2002) and has the economic incentive to increase output (Bode 2002; Burtraw et al. 2001), while an absolute target does not (Philibert & Reinaud 2004). Yet Ellerman (2005) finds little support for this argument from the US experience.

Coverage

There is a common understanding that the wider the coverage, the greater the potential for individual entities in lowering overall costs (Baron & Bygrave 2002; Commission of the European Communities 2000). Yet, by considering uncertainty and monitoring cost, a trading program may initially cover only some sources of the targeted emissions (Ellerman et al. 2003). In practice, all the emissions trading schemes so far only cover some of the emissions (Philibert & Reinaud 2004): see the EU ETS (Egenhofer 2007) and the US Acid Rain Program (Ellerman et al. 2003) in particular.

Allocation

How to allocate emission permits is a key decision in emissions trading schemes (Ekins & Barker 2002). Grandfathering and auctioning are two main methods used by governments internationally (Huang & Lee 2009). Grandfathering distributes free allowance to participants on the basis of historical emissions (Huang & Lee 2009). The principal reason for grandfathering allocations is to ‘buy’ acceptance and support from existing parties (Egenhofer 2007; Markussen & Svendsen 2005; Tietenberg 2002). But it may create an incentive for polluters to be as dirty as possible in the periods prior to setting the allocation. Many studies support auctioning because it is more efficient (Fullerton & Metcalf 2001; Goulder et al. 1999), technically preferable, more transparent and simpler (*Questions and Answers on the Revised EU Emissions Trading System* 2008). In addition, it can raise revenue for governments (Ackerman & Stewart 1985) and provide the greatest incentive for investing on low-carbon technology (*Questions and Answers on the Revised EU Emissions Trading System* 2008). However, Vesterdal & Svendsen (2004) argue that auctioning allowances may not be politically feasible. Experience from the US and EU trading schemes indicate that allocation choices need to consider both political and economic feasibility (Boemare & Quirion 2002).

Banking and borrowing

Banking, the transfer of unused allowances to future years, has been allowed in most emissions trading programs (Boemare & Quirion 2002). Theoretical and practical experiences show that banking reduces overall compliance costs by creating inter-temporal flexibility because cost savings can be traded over time (Akhurst et al. 2003; Hansjürgens 2005; Kling & Rubin 1997; Schleich et al. 2006). Heavy use of banking in the US SO_2 trading led to early reductions and fewer compliance costs (Ellerman et al. 2003; Tietenberg 2003). Conversely, the lack of banking terms may lead to enormous price fluctuations, such as in the EU ETS (King 2008b) and the RECLAIM program (Ellerman 2007). Nevertheless, it is recommended to limit both the number of permits that can be banked and the longest term allowed for banking so as to avoid the risk to future GHG reductions which could be raised by accumulating a large bank of allowances (Boemare & Quirion 2002; Philibert & Reinaud 2004).

Borrowing, the flexibility of allowing firms to delay commitment, is not clearly allowed in any emissions trading experiences as it will cause difficulty in ensuring targets are met (Boemare & Quirion 2002). Godard (2001) points out that borrowing may create two problems: firms delay their emission reductions for several years and then ask to renegotiate reduced commitments to their benefits.

Linkage

Linkage in a national ETS includes linking with other relevant policy instruments at national level and with other emissions trading schemes at the international level (Mavrakis & Konidari 2003). As it is too expensive to include all plants and households in the carbon trading scheme, Svendsen & Vesterdal (2003) suggest using a tax or some other measures on the non-participating plants and households to make sure that they are faced with approximately the same cost. When linking other trading schemes, monitoring, accounting and verifying, compliance mechanisms and mutual recognition of trading units are essential elements to be considered (Blyth & Bossi 2004; Haites & Mullins 2001; Peterson 2004).

Compliance system

Akhurst et al. (2003) are convinced that data quality is the key to a successful trading system, especially at the early stage of a climate program. The US EPA measures emissions by requiring most emission sources to install Continuous Emission Monitoring (CEM) equipment and creating a data registry to collect, audit, manage, and disseminate emissions data (Yang et al. 2003).

To ensure that the GHG emissions do not increase, Svendsen and Vesterdal (2003) propose that a participant whose emissions exceed its permits must be fined and then reduce the excess amount in the next year. Strict and foreseeable penalties make the US Acid Rain Program successful in complying with the terms (Commission of the European Communities 2000; King 2008b). However, Shell failed to meet its target because no sanctions were taken for non-compliance (De Coninck & Van der Linden 2003). Cheating with emissions data is another great threat to compliance (Peeters 2006). There is, therefore, a need for a well-developed compliance system of monitoring and enforcement, including anti-corruption measures.

The literature shows that the design of an emissions trading program has a great influence on the operation of the ETS. To the best knowledge of the author, no literature has examined the design of the existing emissions trading programs and their impacts on the emissions trading practice in China. Furthermore, an ETS to reduce carbon emissions has not been in place in China. Previous experiences and lessons of designing emissions trading programs will eventually help to design an efficient carbon trading framework for China.

2.5.6 Lessons from early trading schemes

Much literature has reviewed the lessons learned from SO_2 trading programs to apply them to GHG trading (Burtraw et al. 2005; Ellerman 2005; Ellerman et al. 2003; Environmental Law Institute 1997; Harrison et al. 2008; Kruger 2005a; Stavins 1998; Tietenberg 2003). Harrison et al. (2008) discuss the important policy issues for GHG emissions trading by studying the US cap-and-trade programs for conventional air pollutants, including SO_2 and NO_X. Parsons et al. (2009) examine the performance of the EU CO_2 market and the US SO_2 market when designing a US market for CO_2.

At the same time, several researchers argue that the climate change issue is different from conventional air pollution problems because of differences in sources, science, mitigation options and economics (Johnston et al. 2008; Kruger 2005a). SO_2 is a more conventional pollutant that had been long regulated before the emissions trading program started (Ellerman & Buchner 2007) and it is a regional problem while CO_2 is a global problem (Ellerman 2005). Moreover, the abatement cost for CO_2 is likely to be much more expensive than that for SO_2 because the installation of scrubbers is an option for reducing SO_2 emissions but not for all GHGs (Johnston et al. 2008).

Nonetheless, 'although the US SO_2 and the European Carbon market are likely to differ in some key issues, the US experience provides important insights that help model the stochastic part of the price path' (Benz & Trück 2006, p. 6). As emissions trading is not widely explored in Europe, Benz and Trück (2006) summarize some experience from the US SO_2 trading market before finding the price drivers and the potential impact on price for the European carbon market. Johnston et al. (2008) examine the valuation implications of SO_2 emissions allowances instead since the data necessary to examine the valuation implications of GHG emissions allowances is not yet available. They believe that there are similar characteristics between the SO_2 and GHG emissions trading markets though they have different scientific and economic attributes. Kruger (2005a) further identifies five aspects from the literature about the modifications that would be needed to make SO_2 trading program suitable for GHG trading: GHG trading would be an economy-wide program; all the GHGs should be covered to achieve cost-effectiveness; auctioning, flexible mechanisms of reducing price risks and international trading should be considered in a GHG trading system.

In practice, the SO_2 programs have had a great influence on the EU ETS, as noted by EU officials and others (Christiansen & Wettestad 2003; Delbeke 2003; Dimas 2005; Zapfel & Vainio 2003). Hence the EU ETS and the US SO_2 program share many characteristics (Johnston et al. 2008). Ellerman and Buchner (2007), however, summarize four significant differences. First, the EU ETS is much larger, covering more sources and more emissions. Second, the allowances price in the EU ETS is much higher. Third, the EU ETS has a highly decentralized implementation and has been considered as a multinational system. Last, the emissions are different in origins and impacts.

Therefore, 'there is general agreement that the SO_2 program "prove the concept" of emissions trading for a greenhouse gas program' (Kruger 2005a, p. 3) and certain features of the SO_2 program could be modified for a GHG trading program after analysing the similarities and differences between SO_2 and GHG_S. Finally, there is so little experience of large-scale programs that the SO_2 emissions trading schemes are the only existing air pollutant emissions trading in China. On the grounds that this is the best available data for emissions trading in the Chinese context, and the extrapolation has been used elsewhere, and across jurisdictions, it is argued that deriving lessons from SO_2 is justified.

2.6 A comparison of policy instruments

Determining which policy option is the best depends on the context, such as the pollutant to be regulated, the structure of the industry and the likely acceptance by stakeholders (Soleille 2006). By analysing the lessons from US SO_2 trading, Stavins (1998) concludes that the best instrument depends on characteristics of the specific environmental problem, and the social, political and economic context in which the instrument is to be implemented. Stavins (1997) puts forward several criteria for assessing climate change policy instruments: efficiency, cost effectiveness, dynamic effects on technological change, distributional equity and political feasibility. Stavins (1997) proposes that the ultimate test will be whether it is scientifically effective, economically rational, and politically feasible. Furthermore, Stavins (1997) points out that since the cost of addressing the threat of climate change will be extremely high, the relative cost effectiveness of policy instruments becomes the principal criteria. A comparison of policy options is given in Table 2.4.

Both carbon tax and carbon emissions trading are market-based policies that aim to internalize the costs of emitting GHG_S (Shrum 2007). Compared with traditional subsidies and command-and-control regulations, both instruments have been confirmed to be more effective in reducing pollution (Ekins & Barker 2002; Shrum 2007). By reviewing current studies on climate change policy, it is also extremely clear that market-based policies are far better than non-market regulations and mandates in reducing GHG_S at the lowest cost (Shrum 2007).

A tax and an ETS are different in their adjusting ways when costs change unexpectedly (Pizer 2002). A permits system adjusts by allowing the permit price to rise or fall while holding the emissions level constant. A tax system adjusts by allowing the level of total emissions to rise or fall while holding the emissions price constant. In perfect market conditions, tax and quantity controls are equivalent if correctly designed, and can produce the same price level and quantity of emissions (Ekins & Barker 2002; Pezzey 1992; Stavins 1997; Stern 2007; Weitzman 1974). But markets are imperfect, so different policy instruments will have varied efficiency and need to be chosen according to the specific purpose (Stern 2007). An emissions tax may not be the most effective approach as it does not engage all of the available methods for emissions control (Nielson 2010). If the tax revenues were not redistributed, carbon taxes may lead to higher cost to polluters than command-and-control regulations (Keohane et al. 1997). Meanwhile, experience in the US has shown that emissions trading can reduce costs and achieve environmental goals at the same time, and it is applicable for GHG trading (Ellerman 2005).

After examining all the instruments, Grubb (1990) concludes that the tradable emission permits system may be the most promising policy and it is efficient in abating global warming. Philibert and Reinaud (2004) support emissions trading because there is no local environmental effects of most GHG_S, and lowering the cost

Table 2.4 Comparison of policy instruments

Criteria	Regulation	Subsidies	Emissions Taxes	Emissions Trading
Certainty over cost?	No	High	High	Low where no price limits are set. Medium with price limits.
Transparency of costs (costs to whole economy easily and accurately identified)	Very low	High - where public accounts allow this, otherwise low	High	High. Emissions permit price is publicly determined through market process.
Certainty over emissions	None	Depends on subsidy but generally high	Very low to none	High if no upper price limits apply. Low to medium If price limits apply and upper permit price is too low.
Efficiently encourages least-cost emissions reduction across economy	No	No	Yes, up to the level of the tax.	Yes over short and long term as all participants able to enact lower cost emissions reductions methods first and then proceed to more costly methods.
Ability to respond to new scientific, technical, economic or regulatory developments and information	Low	High	Low	High
Ability to raise revenue	No	None	Very High	Low if large number of permits distributed free of charge. High if permits auctioned.
Incentives for R&D in clean technology	Yes and no. Technology standards encourage adoption of a particular technology but no incentive beyond that point	High	Yes, if tax is high enough, and not applied in a way that precludes any particular emissions reduction method	Yes: as emissions cap tightens, incentive increases.

Criteria	Regulation	Subsidies	Emissions Taxes	Emissions Trading
Harm to competitiveness	Somewhat	None	Low, due to low level of existing taxes. High, if tax is high enough and alternative locations have no tax or other environmental controls.	To date low, as existing schemes have not featured a high enough emissions permit price to warrant large-scale relocation or alternative investment in other countries.
Practicable or political obstacles to implementation	Yes, setting the level is difficult. Regulators do not have sufficient information to accurately set regulation in most instances.	Low, policy is easily implemented	Very low, policy design is simple and generally easy to implement. However setting optimal tax level difficult.	High, as establishing a practicable permit allocation method and reasonable emissions cap is difficult. Scheme design has to be carefully thought out and this may be time consuming.
Political feasibility (low share of regulatory burden falling on emitters)	High as cost spread across all consumers of a particular product	High, as costs to consumer and firm are reduced	Very low. New taxes and changes to established taxes very unpopular. Medium, with tax switch on compensation.	Low as burden falls on highest emitters who lobby for changes in scheme.
New institutional requirements	Minimal	None	Minimal	Very high, but existing securities markets and regulation can be adopted to establish scheme.
Fairness across income groups (limiting impact on low income groups)	High as cost spread across all consumers of a particular product	High. Such households are usually beneficiaries	Very low. Regressive for low income households.	Low, as increase in costs can be regressive to low income households.

Data source: adopted from Nielson (2010, pp. 22-24)

of emission reductions is very important. Moreover, global climate change will eventually need a global emissions trading system to achieve the least cost and facilitate global participation. Akhurst et al. (2003, p. 1) are convinced that:

> Trading should be a better way of achieving the world's objectives than the suggested alternatives – command and control regulation which imposes the same standard on everyone, irrespective of the costs they face or taxation, which just raise the price to

> everyone, irrespective of whether they have a cheap alternative or not. There are both blunt instruments, whereas emission trading is a precision tool.

However, Akhurst et al. (2003) overlook one important factor in asserting that taxation 'just raise the price to everyone', without considering what one does with the taxation revenue.

Carbon tax and emissions trading, as market-based instruments, are more efficient than other instruments in reducing carbon emissions. The emissions trading approach is acknowledged as potentially the most cost-effective one among the four main instruments. Considering the typical characteristic of climate change problems and the principal criteria of choosing a climate change policy, it is suggested that emissions trading is the best policy for reducing carbon emissions theoretically. But whether it is the best choice in the context of China at this stage needs to be examined and assessed carefully.

2.7 Conclusion

Due to the existence of 'externalities' and the nature of 'global public good', climate change can be seen as the greatest market failure. Therefore, government policy instruments are needed to address the climate change problem. Generally, four types of policy options have been considered for addressing environmental issues: command-and-control regulations; subsidies; taxes; and emissions trading.

Command-and-control regulations have been used extensively to improve the environment, but economic incentive instruments have become more widely used. Empirical studies of command-and-control regulations have confirmed that they are generally far less cost effective than other economic instruments and have many negative economic impacts on some sensitive sectors, indicating they are not optimally effective policy in reducing carbon emissions.

Pigovian subsidies are not favoured by economists generally as they go against the polluter pays principle. In practice, a large number of subsidies have been used for environmental purposes. Meanwhile, due to the rationale of supporting economic growth, fossil fuel-based subsidies are widespread, which inevitably contributes to the increase in carbon emissions and climate change. In order to achieve carbon reductions, subsidizing the alternatives (clean or less carbon-intensive energy sources) along with removing the harmful fossil fuel subsidies should be employed simultaneously. However, due to the uncertainty on the emissions levels, they could not be used as the central policy for mitigating the carbon emissions.

A carbon tax, as a market-based instrument, has been supported by some economists for reducing carbon emissions. It has been widely applied in practice as well, particularly in some European countries. Empirical studies show that although a carbon tax would negatively impact on the economy and distributions, the negative effects could be alleviated by using the tax revenue to subsidize households or offset other distortional taxes. Therefore, a carbon tax may be an acceptable policy instrument for achieving carbon reductions.

Emissions trading is potentially the most effective and efficient policy in reducing carbon emissions. It is more cost effective and more certain about emissions levels, and more likely to link with other countries' carbon reduction programs than other instruments. Neither a carbon tax nor carbon trading has been used in China to reduce carbon emissions to date. China also has very limited experiences in designing and implementing emissions trading programs for other pollutants. Whether an emissions trading program would be the most appropriate choice in China at this stage and whether it could help China achieve the carbon reductions target remain unknown and need to be explored with convincing evidence and rigorous analysis.

Chapter 3 Emissions control policies and practice in China

3.1 Introduction

Chapter 2 reviewed the main policy instruments for mitigating carbon emissions, including command-and-control regulations, subsidies, taxes and emissions trading. It was pointed out that command-and-control regulations are not optimally effective, and subsidies could not be used widely as a central policy, while carbon tax and emissions trading, as market-based instruments, could be both efficient and effective in reducing carbon emissions. Particularly, emissions trading it was argued, could be the most effective policy for addressing the climate change problem in terms of achieving targets.

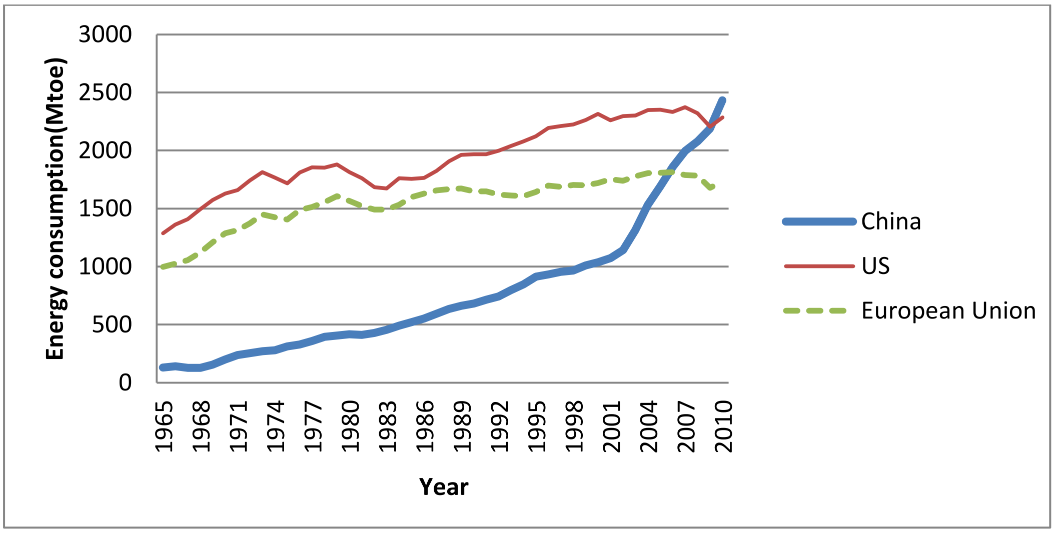
This chapter will review the context of China, providing comprehensive background information related to the climate change problem and emissions trading policy in China. Section 3.2 will present the energy consumption, carbon emissions and climate change situations in China. Section 3.3 will first introduce the objectives and principles of China in relation to the climate change issue, and then summarize the policies that China has employed and the relevant achievements in mitigating carbon emissions. Emissions trading practice in China, which is represented by the case of Taiyuan SO_2 emissions trading program, will be discussed in Section 3.4. Section 3.5 will compare the Chinese context with the western context concerning environmental policy to identify the necessary considerations in selecting policy instruments for China.

3.2 The policy context

3.2.1 China's energy consumption and trend

According to the BP Statistical Review of World Energy (2011), in 2010 China surpassed the US as the largest energy consumer in the world. China then consumed about 2432.2 million tonnes of oil equivalent (Mtoe), which accounted for 20.3% of global energy consumption and was 146.5 Mtoe more than that of the US. While the

EU countries experienced relatively small increases and even some decreases in energy consumption, consumption grew vigorously in China, especially after 2001. During 2010 energy consumption surged by 11.2% (BP Statistical Review of World Energy 2011). Figure 3.1 presents China's energy consumptions from 1965 to 2010. It should be pointed out that per capita energy consumption in China was still only 1.77 toe in 2010, much less than that of 7.45 toe in the US, 9.42 toe in Canada and 4.9 toe in Russia (Li 2011). As the prospects of further economic growth remain strong in China, total energy consumption is projected to increase at an average annual rate of 3.1% between 2007 and 2035 (EIA 2011a).



Data source: BP Statistical Review of World Energy (2011)
EU: excludes Estonia, Latvia and Lithuania prior to 1985 and Slovenia prior to 1991.

Figure 3.1 China's energy consumption from 1965 to 2010

Primary energy sources generally refers to coal, oil, natural gas, nuclear, and hydroelectricity and other renewables (BP Statistical Review of World Energy 2011). The first three kinds of energy are from fossil fuels that contribute to carbon emissions, with coal being the most polluting source of energy, while the last three kinds are clean energy[10]. As different types of energy play different roles in carbon emissions, and market mechanisms will have a different effect on each of them, it is necessary to have a good understanding of the energy consumption structures and patterns in China, each of which will be discussed below.

[10] Clean energy in this thesis refers to carbon-free energy.

Coal

Coal use accounted for more than 70% of China's total primary energy consumption in 2010 (Figure 3.2). China is both the largest consumer and producer of coal in the world (BP Statistical Review of World Energy 2011). In 2010 China consumed 1713.5 Mtoe of coal, representing 48.2% of the world total and was responsible for about two-thirds of the increase in global consumption. Coal consumption has been on the rise in China over the last ten years, with an overall increase of 132.5% since 2000. Coal extraction also rose significantly during this period and accounted for 48.3% of the world total in 2010 (BP Statistical Review of World Energy 2011). There are 27 provinces in China that produce coal, with northern China, especially the Shanxi and Inner Mongolia provinces, containing most of China's easily accessible coal and almost all of the large state-owned mines (EIA 2010a). Although the US Energy Information Administration (2010a; EIA) forecasts that the share of coal in China's total energy consumption will fall to 47% by 2035 due to an increase in energy efficiency and a reduction in carbon intensity, coal will remain the leading source of energy in China. With the strong economic growth, it is expected that China's coal consumption will increase by 1925.28 Mtoe in 2020 and 2832.48 Mtoe in 2035, with an average annual increase rate of 2.6% from 2007 to 2035 (EIA 2011a).

Oil

China is currently the world's second largest oil consumer, after the US. Consumption of oil was 9057 thousand barrels per day (bbl/d) in 2010, accounting for 10.6% of the world total and with an increase of 10.4% from 2009 (BP Statistical Review of World Energy 2011). The use of oil nearly doubled in China during 2000–10. Oil is also the second largest energy source in China, accounting for 17.62% of the country's total consumption (BP Statistical Review of World Energy 2011). In addition, China is highly reliant on oil imports. In 2009 China overtook Japan and became the second largest net oil importer in the world behind the US (EIA 2010a). It is projected that the liquid fuels consumption in China will rise to 10.6 million bbl/d in 2012 and 16.9 million bbl/d in 2035 (EIA 2011a, 2011b).

Natural gas

Historically, natural gas has not been a major fuel in China, although both the amount of absolute consumption and its share in the country's energy consumption are increasing. The use of natural gas in China increased from 24.5 billion cubic metres in 2000 to 109 billion cubic metres in 2010, accounting for 4.03% of the country's total energy consumption (BP Statistical Review of World Energy 2011). Although most of the natural gas is consumed by industries (45% in 2007 according to the National Bureau of Statistics of China), the growth of consumption in recent years is due to the increasing demand from the power, utilities and residential sectors (EIA 2010a). Because of the relative environmental benefits of natural gas, China plans to boost the share of natural gas in total energy consumption to 10% by 2030 to relieve high pollution from a high reliance on coal (EIA 2010a). According to the EIA (2011a), the consumption of natural gas will grow 5% per year on average from 2007 to 2035 and will triple by 2035.

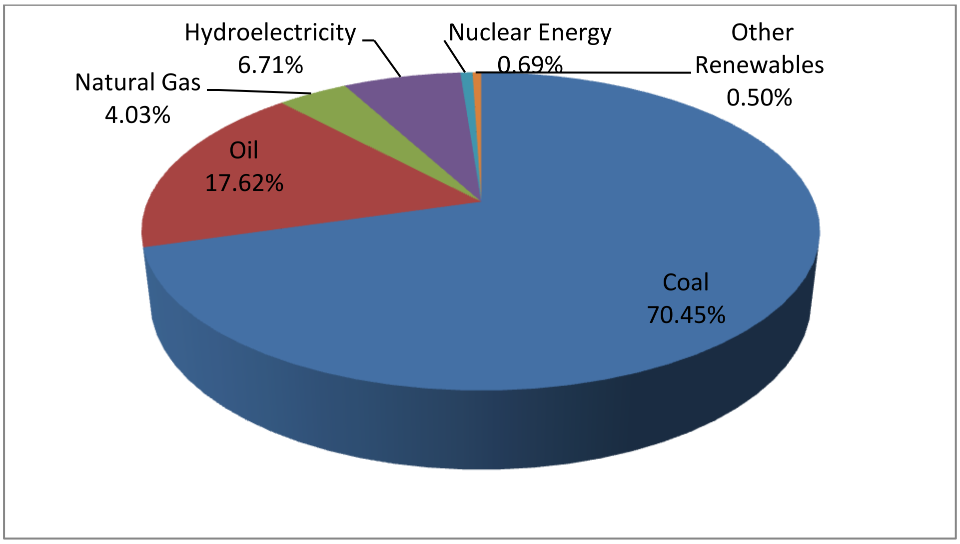
Nuclear, hydroelectricity and other renewable sources

Currently, China's nuclear energy consumption is still very small, only accounting for 0.69% of the total energy consumption in 2010 (BP Statistical Review of World Energy 2011). But China is actively promoting nuclear power as a clean and efficient source of electricity generation and 70 GW of nuclear capacity has been planned to be added by 2020 (currently around 9 GW) (EIA 2010a). EIA forecasts that about 598 000 GWh will be generated by 2035 in China, growing at an annual rate of 8.4% (EIA 2010a).

In 2009 China generated 82% of its electricity from fossil fuel sources, particularly coal (EIA 2010a). This dominance is expected to continue (EIA 2010a). However, the Chinese Government did make efforts to promote renewable energy use such as electricity from large hydropower projects or windmills. The investment in renewable energy projects in China increased from around $120 billion to $160 billion between 2007 and 2010, making China the largest investor in such projects in the world in 2010 (EIA 2010a).

China was the world's largest producer of hydroelectric power in 2010. It generated 163.1 Mtoe electricity from hydroelectric sources, representing 21% of its world total generation (BP Statistical Review of World Energy 2011). Hydroelectricity in

China is expected to increase with the development of projects such as the Three Gorges Dam, which is the largest hydroelectric dam in the world (EIA 2010a). The State Energy Bureau of China expects an increase in hydro capacity from around 197 GW in 2009 to 380 GW by 2020 (EIA 2010a). Wind is the second leading renewable source for power generation, with China being the world's fifth largest wind power producer, generating 25 Bkwh in 2009, growing by 100% from 2008 (EIA 2010a). The National Development and Reform Commission of the People's Republic of China (NDRC) aims to increase the wind capacity from 16 GW in 2010 to 100 GW by 2020 (EIA 2010a).



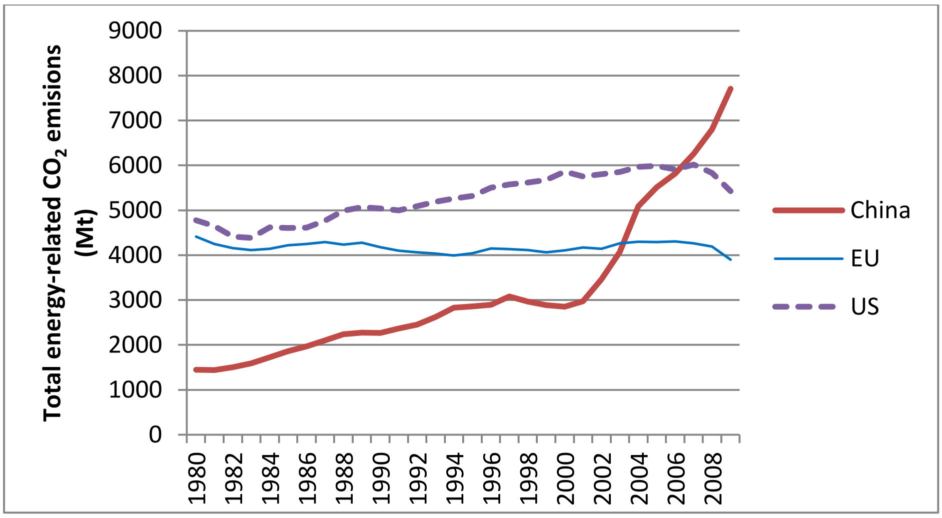
Data source: BP Statistical Review of World Energy (2011)

Figure 3.2 Total energy consumption in China, by type (2010)

Overall, China is the world's largest energy consumer even though per capita energy consumption is still very small. Coal is the largest source, followed by oil and natural gas, while clean energy only accounts for a relatively small share and remains underdeveloped. Total energy consumption and the consumption of each type of energy are projected to increase in China in the next 25 years due to energy demands resulting from a fast developing economy. With the development of clean energy and China's target for reducing pollutions and controlling carbon emissions, the share of coal in total energy will decrease but it will still be the dominant resource in China. The increasing use of fossil fuels will lead to further increases in carbon emissions.

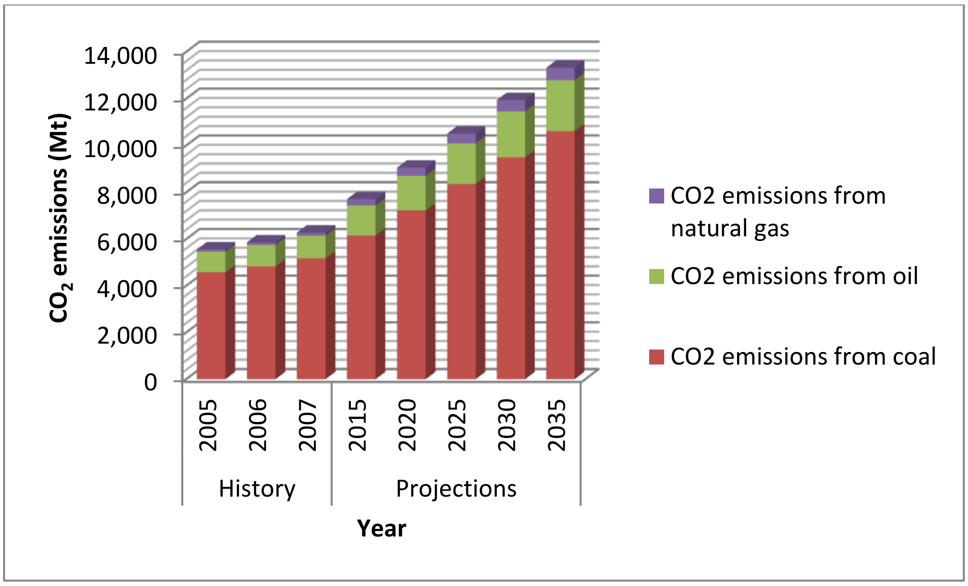
3.2.2 Carbon emissions from China

As a consequence of being the world's largest energy consumer, China is also the world's largest CO_2 emitter. Statistics from the EIA show that about 7707 Mt of CO_2 emissions were emitted from the consumption of energy in China in 2009, accounting for a quarter of global energy-related CO_2 emissions, about 2282.3 Mt more than that of the second largest emitter, the US (EIA 2010b). However, in 2009 the per capita energy-related CO_2 emission was 5.823 t in China, equivalent to only 33% of the US and 1.3 times the world average (EIA 2010b). Nevertheless, Chinese carbon emissions have been growing strongly in the past decades, especially since 2000, as the country built many new coal plants to power its economic growth (Figure 3.3). From 2000 to 2009 the total energy-related CO_2 emissions in China almost tripled while emissions from the world only increased by 26.57%. Particularly, CO_2 emissions rose 13.33% in 2009 compared with 2008 (EIA 2010b). Due to the energy structure features, coal is the largest source of CO_2 emissions in China, followed by oil and natural gas (Figure 3.4) (EIA 2011a).



Data source: EIA International Energy Statistic (2010b)

Figure 3.3 Total energy-related CO_2 emissions in China from 1980 to 2009



Data source: EIA's International Energy Outlook 2010 (EIA 2011a)

Figure 3.4 Energy-related carbon dioxide emissions in China (2005–35)

EIA projects that CO_2 emissions in China will increase by 2.7% per year from 2007 to 2035, while the annual increase rate for the world average is 1.3%, indicating that China has strong economic growth and still will be heavily reliant on fossil fuels, especially coal (Figure 3.4) (EIA 2011a). More specifically, CO_2 emissions from natural gas will increase fastest and from coal increase slowest, at annual rates of 5% and 2.6% respectively (EIA 2011a). In sum, CO_2 emissions have increased rapidly in the past decades and will continue to increase strongly in the future. As scientific evidence has confirmed that CO_2 emissions are the major cause of climate change (IPCC 2007b), the rapid increase in CO_2 emissions in China will have important implications for global warming and climate change.

3.2.3 Climate change in China

Our planet has experienced noticeable changes over the past 100 years, China is no exception. The major observed evidence of climate change in China includes changes in temperature, precipitation, extreme climate/weather events, sea level and glaciers (NDRC 2007). For instance, the national average surface air temperature rose by 0.5–0.8℃ over the past 100 years, slightly higher than the world average (The People's Republic of China 2007). Extreme weather/climate events, such as drought in northern and northeastern China and flood in the middle and southeastern China, have occurred more frequently and severely over the last 50 years (The

People's Republic of China 2007). Meanwhile, the sea level rose at an average rate of 2.5 mm/year. Chinese scientists project that climate change in China will further intensify in the future (The People's Republic of China 2007). In particular, the annual average air temperature will increase by 1.3–2.1℃ by 2020 and 2.3–3.3℃ by 2050, from the 2000 level.

As a developing country, China is one of the countries most vulnerable to the adverse effects of climate change, mainly in the fields of agricultural and livestock industries, forestry and other natural ecosystems, water resources and coastal zones (Heggelund 2007; IPCC 2007a). Climate change has already caused negative effects in those fields in China. For example, because of drought and high temperature in some parts of the country, agricultural production has become more unstable and livestock breeding has been damaged severely (NDRC 2007). Future climate change will further increase the adverse impacts. The changes of water resource distribution over China will significantly intensify the imbalance between supply and demand of water resources in some areas such as Inner Mongolia in the next 50 to 100 years (Zhang & Wang 2007). In addition, climate change will also produce far-reaching impacts on society in many areas, causing huge losses to the Chinese economy (NDRC 2007). For instance, climate change may increase the chances of diseases occurring and spreading, with the ensuing dangers to human health.

Therefore combating climate change is in the best interests of China. Actually, China has paid great attention to the climate change problem and has carried out many polices and measures to control carbon emissions and mitigate climate change, as demonstrated in the next section.

3.3 The existing climate change policies in China

3.3.1 Objectives of China to address climate change

On 4 June 2007 the NDRC issued China's National Climate Change Program, which is the first comprehensive climate change strategic plan in China (NDRC 2007). It was mandated under the UNFCCC and outlined the objectives, basic principles, key areas of actions, as well as policies and measures, to mitigate climate change by 2010.

The NDRC states that

> the strategic goal of China to respond to climate change is to make significant achievements in controlling greenhouse gas emissions, to enhance the capability of continuous adaptation to climate change, to promote climate change related science, technology and R&D to a new level, to remarkably raise public awareness on climate change, and to further strengthen the institutions and mechanisms on climate change (NDRC 2007, p. 26).

This strategic goal suggests that China wants to mitigate carbon emissions and address the climate change issue. Specifically, China has voluntarily committed to reduce carbon emissions per GDP by 40–45% by 2020, compared to its 2005 level at the Copenhagen Summit 2009 (Wen 2009).

3.3.2 China's policies to address climate change

China has carried out many policies and measures, ranging from laws, regulations, subsidies, education, administration through to international cooperation to reduce carbon emissions and ultimately mitigate climate change (The State Council Information Office 2008; Zhang & Zheng 2007). Table 3.1 summarizes some selected policies and measures for addressing climate change in China.

Laws and regulations

China has introduced laws to address climate change. For example, the 'Renewable Energy Law of the People's Republic of China' was adopted in February 2005 (Sandall et al. 2007). In addition to setting duties and obligations, and policies and measures, this law commits the government to achieving a target that the share of renewable energy in total energy use will reach 16% by 2020 (Sandall et al. 2007). In August 2005 the State Council issued the 'Notification on the Immediate Priorities for Building a Conservation-oriented Society and Several Opinions on Accelerating the Development of Circular Economy'. In August 2006 the State Council issued the 'Decision to Strengthen Energy Conversation' (NDRC 2007). All those documents serve as legal guarantees to ensure the capability of China in mitigating climate change.

Command-and-control regulations, such as standards, mandates and so on, have been widely used in China to reduce carbon emissions. For instance, the NDRC set mandatory fuel efficiency standards for passenger cars and light-duty vehicles, taking effect in 2005 and 2008 respectively (IEA 2010a). A national building energy standard was put into effect in August 2008: this requires reducing a building's total operation load by 50% by 2010 based on a building's energy consumption during the 1980s (IEA 2010a). In early 2007 the NDRC issued orders to retire all small and inefficient plants in various industrial subsectors (IEA 2010a). Coal-fired power plants with less than 50 MW capacity and with a capacity between 50 and 100 MW that had been in operation for over 20 years were required to be closed by 2010 (IEA 2010a). Thus about a total of 40 GW of small, inefficient coal-fired plants would have been retired by 2010 (IEA 2010a).

Subsidies and financial mechanisms

A series of subsidies and financial initiatives have been employed by the Chinese Government to promote sustainable development, including grants, preferential treatment, preferential tax, tax reduction or exemptions and so on (Sandall et al. 2007). Preferential treatments, such as loan interest discounts, reduction of enterprise income tax, accelerated depreciation and so on, have been provided to encourage the use of energy-saving technology or for purchasing energy-saving equipment (Sandall et al. 2007). The preferential tax policy for renewable energy, which took effect in 2003 and was expanded in 2007, stipulates that the income tax rate for foreign investment in either biogas or wind energy production is cut from 33% to 15%, and both producers and consumers of renewable energy benefit from preferential import rate for importing 'green' equipment (IEA 2010a). Subsidies, as well as tax reductions or exemptions of value-added tax (VAT) or import tax have been provided to the fuel ethanol producers since 2002 (IEA 2010a). In 2006 the subsidy was RMB¥1373/t of fuel ethanol produced. According to the 'Reduced VAT for Renewable Energy policy', VAT for wind power has been reduced from 17% to 8.5% since 2001 and for biogas has been cut to 13% since 2003 (IEA 2010a).

Financing climate change research is also a form of indirect subsidy. A number of research projects have been implemented in China to provide a scientific support for developing a national climate change policy and favoring the negotiation of China under the UNFCC. These include a Study on Formation and Prediction Theory of Key Climate and Weather Disasters in China, and Carbon Balance Study in China's Land and Offshore (NDRC 2007). According to the National Science and

Technology Plan for the 11th Five-Year Plan period, more than RMB¥7 billion would have been spent on scientific research into energy conservation and emission reduction by the end of 2007 (The State Council Information Office 2008). In addition, a large number of national-level scientific research bases and observation network systems, such as the National Climate Monitoring Network, have been set up in an attempt to enhance the capability of the Chinese Government to deal with climate change issues (The State Council Information Office 2008).

Education, training and public awareness

China has intensified its efforts to promote education, training and public awareness concerning the environment and climate change in recent years. It has organized various basic knowledge lectures on climate change and provided climate change training courses for policymakers at central and provincial levels (NDRC 2007). Large-scale international conferences or seminars were conducted to raise the awareness of climate change. Since 1992 China has staged 18 sessions of the National Energy Conservation Publicity Week in succession (The State Council Information Office 2008). It has produced a large number of publications on climate change and established an official bilingual climate change website in Chinese and English (China Climate Change Info-Net, http://www.ccchina.gov.cn) to provide comprehensive information on climate change (NDRC 2007; The State Council Information Office 2008). Moreover, China is gradually integrating climate change knowledge into school education. For example, the knowledge of renewable energy has been put into the primary and high schools’ teaching material (The People's Republic of China 2004).

Capacity building

As early as 1990 the Chinese Government set up special institutions to deal with climate change (The State Council Information Office 2008). In 1998 the National Coordination Committee on Climate Change was established to provide guidance for governments on how to response to climate change (NDRC 2007). In 2007 the National Leading Group to Address Climate Change, led by the Chinese premier, was set up to further strengthen the leadership on climate change (The State Council Information Office 2008). This group is responsible for drawing up important strategies, policies and measures and coordinating the solving of major problems related to climate change. Moreover, China has established an Experts Committee to make more scientific decisions on climate change (The State Council Information Office 2008). This committee has contributed greatly in supporting government decision making as well as promoting international cooperation and non-governmental activities. In addition, the Chinese Government is establishing a regional administration system for coordinating the work in response to climate change and strengthening the institutional capacity of local governments at different levels (Sandall et al. 2007).

Table 3.1 Policies and measures for addressing climate change in China

Policy Name	Type	Target	Status	Year
Brightness program	•Policy processes	•Energy production	In force	1996
Reduced VAT for renewable energy	•Financial	•Energy production	In force	2001 (expanded 2003)
Support for fuel ethanol production	•Financial •Incentives/subsidies	•Energy production •Transport	In force	2002
Preferential tax policies for renewable energy	•Financial	•Energy production	In force	2003 (expansion 2007)
Australia–China bilateral cooperation on climate change (MOU)	•Education and outreach •Policy processes •Voluntary agreement	•Framework policy	In force	2003
Wind power concession program	•Incentives/subsidies	•Energy production	In force	2003
Medium and long-term plan of energy conservation: 10 energy conservation programs	•Policy processes •Public investment •Regulatory instruments	•Appliances •Buildings •Industry •Multi-sectoral policy •Transport	In force	2004
Vehicle fuel economy standards	•Regulatory instruments	•Transport	In force	2005 (and 2008)
Asia–Pacific Partnership for Clean Development and Climate			In force	2005
Renewable energy law	•Policy processes	•Energy production	In force	2006 (revised in 2009)
Vehicle excise tax rates	•Financial	•Transport	In force	2006 (amended 2008)

Policy Name	Type	Target	Status	Year
Efficiency upgrade for coal-burning industrial boilers and kilns	•Policy processes •Regulatory instruments	•Industry	In force	2006
Efficiency upgrade for electric motors	•Education and outreach •Policy processes •R&D	•Appliances	In force	2006
Eleventh Five-Year Plan	•Policy processes		In force	2006
Energy efficient products for government procurement – publication of official listing	•Public investment	•Appliances	In force	2006
Energy intensity reduction target	•Policy processes •Regulatory instruments	•Framework policy •Multi-sectoral policy	In force	2006
Expansion of local cogeneration (CHP)	•Public investment	•Energy production •Industry	In force	2006
Fuel-switching and conservation to reduce petroleum use	•Policy processes •Public investment •R&D	•Multi-sectoral policy	In force	2006
Renewable energy development targets	•Policy processes	•Framework policy	In force	2006
Support for biogas projects	•Policy processes		In force	2006
Top 1000 industrial energy conservation program	•Voluntary agreement		In force	2006
Aluminium industry permitting standards	•Regulatory instruments	•Industry	In force	2007
Medium and long-term development plan for renewable energy	•Policy processes	•Energy production	In force	2007
National Climate Change Program	•Policy processes	•Framework policy	In force	2007
Retirement of inefficient plants	•Regulatory instruments	•Energy production •Industry	In force	2007
Efficient lightbulb subsidy program	•Incentives/subsidies •Voluntary agreement	•Appliances	Planned	2008
Hong Kong – tax incentives for environmentally friendly commercial vehicles	•Financial	•Transport	In force	2008
National building energy standard	•Regulatory instruments	•Buildings	In force	2008

Data source: adopted from IEA (2010a)

International cooperation

China has been actively engaging in both bilateral and multilateral cooperation on climate change, such as supporting the activities of the UNFCCC and Kyoto Protocol, joining in influential international organizations relevant to climate change, setting up dialogue on climate change with other countries or regions, cooperating in research on climate change with foreign governments and international organizations and research institutes, participating in technology transfer under the UNFCCC framework, and joining CDM programs and so on (Heggelund 2007; The State Council Information Office 2008). For example, China signed an agreement with the US on energy conservation and renewable energy cooperation, which has helped both countries exchange and cooperate in more than 10 projects in these two areas (The People's Republic of China 2004).

Moreover, China has launched a national tree planting and afforestation campaign[11] as well as other ecology restoration and protection policies, such as pasture restoration and protection, to increase the capacity of forests in reducing GHGs. In addition, the government of China has made the family planning policy a basic national policy to control the growth rate of population, which could contribute to the control of carbon emissions in China indirectly.

3.3.3 China's achievements in mitigating climate change

Some achievements have been made thanks to the policies and measures discussed above. Through strengthening energy conservation, enhancing energy efficiency, optimizing energy mix, improving ecological environment, enhancing adaptation capacity, developing research, raising public awareness and improving administrative capacity, carbon emissions in China have been reduced to some extent (Chandler et al. 2002; NDRC 2007). China has made some positive contributions to the mitigation of climate change.

The energy intensity (energy consumption per million GDP at constant 2000 RMB) in China decreased from 268 tce in 1990 to 143 tce in 2005, declining at an average annual rate of 4.1%. It was calculated that a total of 800 Mtce energy was saved between 1991 and 2005 through adjusting economic structures and improving

[11] However, planting trees and afforestation require water, another resource terribly stretched in China.

energy efficiency, which is equivalent to a reduction of 1800 Mt of CO_2 emissions according to the China's 1994 emissions factor of 2.277 tCO_2/tce (NDRC 2007).

By 20 July 2008, 244 CDM projects from China had been registered with the United Nations, which were expected to save 113 Mt of CO_2 emissions annually (The State Council Information Office 2008). As a result of the CDM projects, renewable energy has been effectively developed while energy intensity has been greatly enhanced in China (The State Council Information Office 2008). In 2010 the utilization of clean energy in China equaled 267.9 Mtce (including hydropower, nuclear energy and renewables), accounting for 7.9% of China's total energy consumption in that year, equivalent to a saving of 610 Mt CO_2 emissions[12] (BP Statistical Review of World Energy 2011).

There are other policies that have made indirect contributions to the mitigation of carbon emissions in China. More than 300 million births have been avoided by 2005 since the family planning policy was carried out (Chandler et al. 2002). Based on the IEA's statistic of per capita CO_2 emissions, it is estimated that the avoided births contributed to about 1300 Mt of CO_2 emission reduction in 2005 (NDRC 2007). According to the estimation of some experts, during the 1980 and 2005 period, afforestation contributed to a 2060 Mt CO_2 saving, forest management resulted in 1.62 Mt CO_2 reduction, and avoided deforestation saved 430 Mt of CO_2 emissions (NDRC 2007).

As can be seen from the above, China has carried out various kinds of policies and measures and made efforts to control carbon emissions and address climate change. However, it is noticed that most of the major policies employed fall into the categories of command-and-control regulations (standards, mandates and enhancing energy efficiency) and subsidies (developing renewable energy), which was argued in Chapter 2 to have some limitations. Though some achievements have been made as a result of the existing climate change policies and measures, CO_2 emissions are projected to continue to increase rapidly due to the strong economic growth and climate change will remain an issue in China. Apparently the existing climate change policies and measures in China are not enough to control carbon emissions and

[12] Calculation is based on the conversion coefficient between Mtoe and Mtce (1 Mtce = 0.697 Mtoe) and China's 1994 emission factor of 2.277 tCO_2/tce (NDRC 2007).

realize sustainable economic growth. In order to achieve the ambitious carbon reductions target committed to at the Copenhagen Summit 2009, more effective carbon policies are thus being called for.

As the largest carbon emitter, China has been under great international pressure to take effective policies to substantially mitigate carbon emissions. Considering the increasing pressure from the rest of the world and in the interest of China itself, it is necessary for China to adopt a major national policy, such as a carbon tax or an ETS. As it has been argued in Chapter 2 that an emissions trading policy is most desirable for addressing the climate change problem theoretically, carbon emissions trading will now be discussed. Whether emissions trading could be implemented effectively in China is not known and so needs to be explored from the existing emissions trading practice. The Taiyuan SO_2 emissions trading program introduced in 2003 provides an opportunity to examine the research Q1:

Is emissions trading a suitable policy for achieving carbon reductions in China?.

3.4 Emissions trading practice in China

3.4.1 Progress of emissions trading practice in China

In China, emissions trading is an economic instrument introduced from foreign countries that has been developed over 20 years (Wang et al. 2009a). The development of emissions trading in China could be generally divided into three stages: the initial trial stage (1987–2000); the pilot exploratory stage (2001–06); and the pilot deepening stage (2007–). The important events of Chinese emissions trading practice during 1987 and 2005 are listed in Appendix 1. Appendix 2 presents the progress on emissions trading practice in China since 2006.

China started emissions trading in the late 1980s. In 1987 the Minhang District, Shanghai carried out a compensated transfer of water pollutants emissions quotas between enterprises (Wang et al. 2009a). On 20 March 1988 the Chinese State Environmental Protection Administration (SEPA) promulgated and implemented 'Interim Measures for Water Pollutants Emissions Permits', whereby control quotas for water pollution can be transferred between the discharge units in same region (Wang et al. 2009a). In 1991 the SEPA conducted air pollutant emissions permit pilots in 16 cities and then implemented policy experiments in air pollutant emissions trading in 1994 in six cities[13] (Yang et al. 2003). However, the trading during this pilot phase was not emission trading in the true sense as all of the 'trades' were organized by the government. In 1999 the SEPA and US EPA co-signed a cooperation file on 'A Feasibility Study on Reducing SO_2 Emissions through Market Mechanism in China', exploring the feasibility of using SO_2 emissions trading in China (Wang et al. 2002). This feasibility study discussed the theories, conditions, foundations and methods of emission trading, and identified the opportunities and barriers to implementing SO_2 emissions trading in the Chinese power sector. Several international seminars and workshops were conducted for Chinese managers and researchers to better understand emissions trading.

During the 10th Five-Year Plan (2001–05) the environmental protection work in China shifted emphasis to total emissions control (TEC) and the SEPA proposed implementing emission permits system to achieve targets (Yan et al. 2009). In this context, several pilot projects were carried out from around 2001. For example, Taiyuan city established an SO_2 emission trading program in 2001 to achieve their SO_2 TEC target at least cost with financial support from the ADB and technical assistance from the US RFF and the CAEP (Yang et al. 2003). In 2002 the SEPA published a notice 'Promoting the Projects of SO_2 Total Emissions Control and Emission Trading Policy in China' and extended the SO_2 TEC and SO_2 emissions trading pilots to seven provinces[14] (Yang et al. 2003). In 2006 the Ministry of Finance and SEPA jointly carried out a survey of emissions trading in some provinces and discussed the possibility of implementing national SO_2 emissions trading pilot in power sectors in China (Wang et al. 2009a). Meanwhile, water pollutants emissions trading pilots had also progressed even though the degree of progress was relatively slower than that of the air pollutants SO_2 emissions trading (Wang et al. 2009a). In summary, emissions trading had been promoted in this stage but trading in the pilots was still organized by the government departments (Wang et al. 2009a) .

During the pilot deepening stage, China significantly increased the emphasis on emissions trading and local governments have been actively involved in emissions

[13] Baotou, Kaiyuan, Liuzhou, Taiyuan, Pingdingshan and Guiyang.
[14] The provinces were Tianjin, Jiangsu, Zhejiang, Shanghai, Shanxi, Henan and Guangxi.

trading, resulting in more trading subjects and policy areas at the national, regional, river basin and local levels (Wang et al. 2009a). In addition, research cooperation on emissions trading has increased and a company that specializes in emissions trading emerged and is trying to create a platform for emissions trading jointly with active assistance from local government (Wang et al. 2009a). At the end of 2007 the third China–US strategic dialogue resulted in the cooperation project of implementing SO_2 emissions trading in the power sectors. In 2007 Hubei Province approved the 'Major Pollutants Emissions Trading Methods in Hubei Province (Trial)' and a platform for emissions trading was set up in Guanggu Property Exchange in Wuhan city, which was the first time emissions trading was in a property rights exchange market (Yan et al. 2009). On 5 August 2008 the Beijing Environment Exchange and the Shanghai Environment & Energy Exchange were established (Wang et al. 2009a). The transaction subjects not only include traditional pollutants such as SO_2 and chemical oxygen demand (COD), but also involve GHGs and other products that can be quantified, indicated and standardized. In September 2008 the Tianjin Climate Exchange was established by the Tianjin Property Rights Exchange Center, the China Petroleum Asset Management Company and the Chicago Climate Exchange, with the transaction objectives covering all kinds of environmental equity products (Wang et al. 2009a).

In summary, even though having been introduced into various sectors and areas, emission trading is still relatively new to China and most of the practices are still in the initial stages. The existing emissions trading practices are limited to water pollutants and SO_2 emissions and no large-scale ETS has been implemented. SO_2 emissions trading, the only existing air pollutant emissions trading in China, with Taiyuan being the most representative area, is considered the most relevant experience that can be studied for future carbon emissions trading in China. More details about this program are provided in the next section.

3.4.2 Case study of emissions trading – SO_2 emission trading in Taiyuan city

Acid rain and SO_2 pollution in China are every severe, with Taiyuan city being one of the most polluted cities. In 2000 the SO_2 emissions in Taiyuan city were 250 000 t and the ambient SO_2 concentrations were 0.2 mg/m^3, three times China's Class II standard of 0.06 mg/m^3 (Wang et al. 2002; Yang et al. 2003). In an effort to improve urban air quality, Taiyuan city committed in the 10th Five-Year Plan (2001–05) to limit SO_2 emissions within 125 000 t by 2005, representing a 50% reduction from the 2000 level (Yang et al. 2003).

In order to control SO_2 emissions and to relieve the effects of acid rain, China has employed various control policies and measures since 1995, including identifying critical control zones [15], limiting the extraction and use of high sulphur coal, promoting SO_2 total emissions control, levying SO_2 emission charges, requiring cities to comply with National Ambient Standards for SO_2 concentrations, adjusting the composition of the power sector and encouraging desulphurisation (Yang et al. 2003). However, due to the high reduction costs and in the light of the successful experience of the US Acid Rain Program, China began to explore the feasibility of using a market-based mechanism, specifically a cap-and-trade approach, to achieve SO_2 reductions at the least cost (Yang et al. 2003). Taiyuan, one of the most representative areas of SO_2 emissions, became the forerunner in the SO_2 emissions trading practice in China.

With the support from ADB, RFF and CAEP, Taiyuan initiated the SO_2 emissions trading project in 2001(Yang et al. 2003). After one year of preparation, the Taiyuan municipal government promulgated the 'Administrative Regulation for SO_2 Emissions Trading in Taiyuan City (Trial)' (Appendix 3), which is the first local legal document for SO_2 emission trading in China and came into effect on 1 January 2003. Initially, 26 key enterprises were identified for participation in the program, whose emissions accounted for over 50% of the city's total SO_2 emissions in 2000 (Wang et al. 2002). Thereafter, all the SO_2 emitters in Taiyuan city were covered by the program. According to the administrative regulation, total emissions control limits of SO_2 in Taiyuan city during every Five-Year Plan period were transferred into corresponding emission caps. Yearly permits in the Five-Year Plan period are allocated to the emissions enterprises for free, and are based on their historic emissions. Permits can be traded and stored, but cannot be used in advance. New enterprises in the current Five-Year Plan period are not given any permits until a new

[15] The government identified key acid rain control and SO_2 pollution control zones known as the 'Two Control Zones' on the basis of areas affected by acid rain and high SO_2 concentrations in 1998.

round of allocations for the next Five-Year Plan, but they can obtain the permits by trading. CEM equipment, accompanied by other auxiliary methods, such as material balance, were used to estimate enterprises' SO_2 emissions (Wang et al. 2002). 'Emissions Tracking System' and 'Allowance Tracking System' were also established to manage emissions data and to supervise permits transactions respectively. Penalties and legal liabilities were applied to enterprises for non-compliance. The Taiyuan Environment Protection Bureau is the supervisor and management institution for the program. The initial policy framework for the Taiyuan SO_2 emission trading program is outlined in Table 3.2.

Table 3.2 The initial policy framework for the Taiyuan SO_2 emission trading program

Scope	26 key pollution sources accounting for 50% of total SO_2 emissions
Region	Urban area (excluding suburban districts and counties)
Total emission target	TEC limits for the 10^{th} Five-Year Plan period –125 000 t
Allocation method	Historic emissions
Legal basis	'Regulation on TEC in Taiyuan City' and 'Administrative Regulation for SO_2 Emission Trading in Taiyuan City'
Trading situations	Training, trading simulation and implementation beginning 1 January 2003
Monitoring and measurement	CEMs, periodic source monitoring, and material balance
Management	Emission and allowance tracking systems

Source: adopted from Cao et al. (2002)

Unfortunately, most of the literature related to the SO_2 emissions trading is only focused on the background and initial introduction of the programs around 2003, without exploring more recent developments and the operation of the SO_2 emissions trading practice in China. Whether the actual performance of these SO_2 emissions trading programs is consistent with the theoretical framework or the same as the initial anticipation remains unknown. The effectiveness of SO_2 emissions trading in China needs to be examined and assessed by the criteria proposed in section 2.5.3, namely, emissions reductions, cost saving, innovation or investment in clean technology and no leakage.

3.5 A comparative perspective of the Chinese context

3.5.1 The policy environment

Sterner (2003) and Opschoor & Turner (1994) argue that a policy does not function in a vacuum, rather, it heavily depends on the overall policy environment in which it is applied. Therefore, it is necessary to know the context of China concerning carbon policy before implementing any carbon emissions trading instrument in China. This section reviews the Chinese context regarding carbon policy from five aspects: economy, market, public awareness, environmental administration and the relationship between government and enterprises.

Since the introduction of market-based economic reforms in 1978, China has been the world's fastest-growing major economy, with consistent real annual GDP growth rates of 9.8% between 1978 and 2007 (Hu 2008). In 2010 China surpassed Japan and became the world's second largest economy after the US (U.S Department of State 2011). China is also the world's largest exporter and second largest importer. However, the per capita GDP in China was only US$4382 in 2010, less than 8% of that of the US and ranking 94th in the world, indicating that China is still a low to middle-income country (International Monetary Fund 2011). The public welfare system in China, including education, health care and social security, falls far behind the world average (Fu 2010). In addition, China has very low per capita resources, a huge proportion of rural and poverty-stricken population, acute economic structural problems and is still low in the global industrial chain (Fu 2010). Even though China is the second largest economy in the world, it remains a developing country, so pressure for economic growth will continue. However, the introduction of a carbon trading system in China may impede economic growth.

Building a well-functioning market economy was formally established as a national policy in the 14th national conference of the Chinese Communist Party in October 1992 and ratified by the 8th National People's Congress in March 1993 (Xie 1995). By 2005 the private sector accounted for as much as 70% of China's GDP and 96% of retailing commodity prices were determined by the market (Engardio 2005; People's Daily Online 2005). However, the government still controls the prices in several service sectors, such as health care, education and transport (Scissors 2009).

Both the capital rate and the exchange rate are regulated by the People's Bank of China. The government retains monopolies in several core sectors of the economy, such as power generation and distribution as well as aviation. According to the 2011 Index of Economic Freedom (2011), China is ranked 135th among 183 countries in the Index of Economic Freedom[16] world rankings, with property rights being weakly protected, indicating that China's market still has a long way to go to achieve full market economy status and property rights in China are limited. While emissions trading is based on the theory of property rights and the principle of the free market, China may lack the resources to implement an ETS.

With the liberalization of Chinese politics and economy, environmental non-government organizations (NGOs) began appearing in China (Ma & Ortolano 2000). The first Chinese environmental NGO emerged in 1994 and approximately 2000 environmental NGOs had registered by the year of 2000 (Schwartz 2004). However, unlike the independent environmental NGOs in the western countries[17], China's environmental NGOs must be sanctioned by the government and have limited autonomy, operating in a highly controlled political space (Ma & Ortolano 2000; Schwartz 2004). In addition, China's environmental NGOs are constrained by insufficient human capital, limited funding and skills, thereby their influence on developing and enforcing China's environmental policy is limited (Schwartz 2004). For example, their activities are largely restricted to advancing government-approved agendas such as raising citizen awareness of environmental problems through education, initiating public clean-up green campaigns and attracting funds from foreign organizations that refuse to work directly with the Chinese Government. The current situation of environmental NGOs in China indicates that the public awareness of environmental issues is still quite low and NGOs could not help much in enforcing an emissions trading policy as an independent third party.

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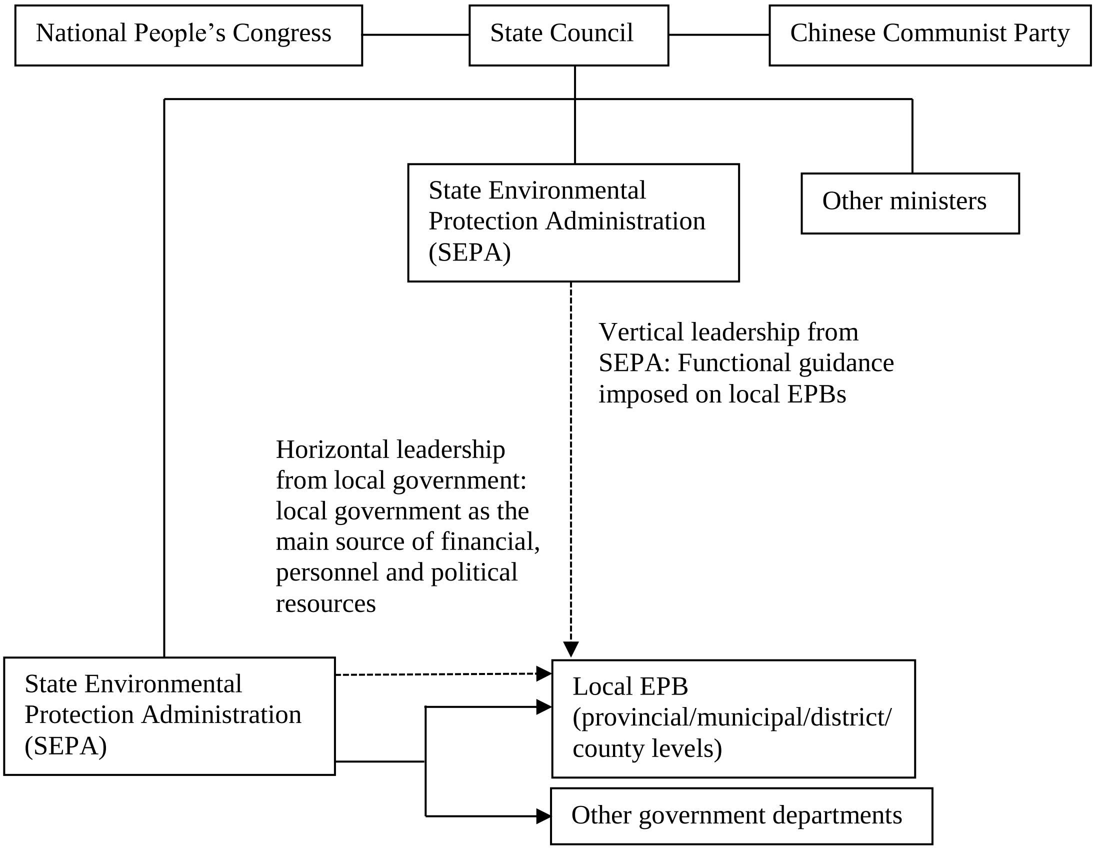
[16] Holmes et al. (2008) define the highest form of economic freedom as one that provides an absolute right of property ownership, fully realized freedoms of movement for labour, capital, and goods, and an absolute absence of coercion or constraint of economic liberty beyond the extent necessary for citizens to protect and maintain liberty itself. Ten components are employed to measure economic freedom: business freedom, investment freedom, trade freedom, financial freedom, fiscal freedom, property rights, government spending, freedom from corruption, monetary freedom and labour freedom (Index of Economic Freedom 2011).

[17] 'Western environmental NGOs include a vast array of organizations with a range of professional skills that address a broad spectrum of issues in an independent and sometimes confrontational manner' (Schwartz 2004, p. 46).

SEPA is China's national environment agency that helps draft environmental laws and regulations but plays a minor role in the daily implementation of environmental rules (Ma & Ortolano 2000). Most of the day-to-day implementation work is managed by Environmental Protection Bureaus (EPBs), which are part of local government and remain a unit in the administrative hierarchy under the leadership of SEPA (Ma & Ortolano 2000). Although decentralization, releasing power from the central government to local governments, is generally regarded as contributing to more effective and responsive government, this is not so in the case of environmental issues (Schwartz 2004). Because the budget and staffing of EPBs are controlled by the local government, the local government naturally has a greater impact on an EPB's daily implementation than the next highest environmental agency in the hierarchy. But local governments tend to focus on short-term economic growth and neglect long-term environmental problems (Schwartz 2004). The dual leadership system of EPBs in China is illustrated in Figure 3.1. In contrast to the situation in China, the national environmental agency in the US, the EPA, is responsible for implementing national laws (Ma & Ortolano 2000). If the state environmental protection agencies are interested in doing the day-to-day implementation work, they must prove that they have the required capacity, such as necessary staff, monitoring capabilities and statutory authority and so on. The complex environment bureaucratic system in China may cause difficulties in administering an ETS.

In contrast with most of other countries, the relationship between government and enterprises in China is different. China has a large number of state-owned enterprises or township and village enterprises (Ma & Ortolano 2000). The privatization reforms have seen the number of private enterprises increase, but many industrial enterprises are still owned by the state, town governments or village committees. While industrial enterprises are the main targets of environmental regulation in China, the participation of local governments in the ownership of these enterprises leads to special challenges for environmental agencies in administering the environmental behaviour of these enterprises (Ma & Ortolano 2000).



Note: Dashed lines refer to influence on local EPB
Data source: adopted from Tao & Mah (2009)

Figure 3.1 Dual leadership systems of local EPBs in China

In summary, China is different from western countries in the situation of economic strength, market conditions, public awareness, environmental administration and the relationship between government and enterprises. It is, therefore, feared that developing countries may lack the resources or the ability needed to implement ideal market-based instruments (Sterner 2003).

3.5.2 Necessary considerations for using carbon emissions trading policy in China

Based on the analysis of current infrastructure and policies for SO_2 control in China, Wang et al. (2002) identify four barriers that need to be considered before implementing SO_2 emissions trading widely in China. First, the current emissions monitoring, verification and reporting are not adequate for supporting a cap-and-trade program in China. Second, the current regulated electricity price makes the Chinese power industry, which is primarily a state-owned industry, difficult to operate in a market-driven trading environment and, further, to adopt effective measures. Third, China is far from a market economy and lacks the market forces to support the use of emissions trading. Last but not least, China has no explicit legal and regulatory authority looking after the implementation of emissions trading.

Similarly, Zhang (2004) proposes environmental, economic, technological, institutional and legal questions when assessing the feasibility of implementing SO_2 emissions trading in China: (1) Whether an emissions trading system is suitable for addressing the SO_2 problem?; (2) Are there enough SO_2 emissions sources with varied abatement costs?; (3) Is the emissions measurement accurate enough?; (4) Is the SO_2 emissions trading system compatible with the existing pollution charge policy?; (5) Whether the market is free enough to implement emissions trading in China?; and (6) Whether the legal authority is adequate for implementing emissions trading in China?. Zhang (2004) and Wang et al. (2002) share similar concerns about emissions trading in China, including emissions measurement, market conditions and legal authority.

In terms of carbon emissions, it has been agreed that emissions trading is suitable for addressing the carbon emissions problem as there are enough carbon emissions sources with varied costs (Ellerman et al. 2003). China is the world's largest CO_2 emitter, so there is no need to worry that carbon emissions sources are not enough or abatement costs are not varied in China. In addition, no pollution charge or other direct environment policy is currently levied on carbon emissions in China, so trading will be harmonious with existing carbon policy. However, the other questions proposed by Zhang (2004) and the barriers suggested by Wang et al. (2002) for SO_2 emissions trading, including emissions measurement, market condition and legal authority, are applied to carbon emissions trading and need to be discussed and analysed before carbon emissions trading is introduced in China.

3.5 Conclusion

This chapter has reviewed the energy consumption, carbon emissions and the current policies on climate change in China. China is the world's largest energy consumer and CO_2 emitter. Climate change in China is noticeable and China has suffered from the adverse impacts of climate change. As energy consumption and CO_2 emissions in

China are projected to increase continuously in the next 25 years, adverse impacts of climate change in China will be intensified. China is under increasing pressure both domestically and internationally to reduce carbon emissions.

China has taken many policies and measures, such as regulations and subsidies, to mitigate carbon emissions. However, the existing policies and measures in terms of reducing carbon emissions in China are found not to be effective enough to realise the commitment made at the 2009 Copenhagen Conference. But the increasing pressure to control continuously growing CO_2 emissions requires China to adopt a more comprehensive and effective carbon policy. Thus a market-based instrument, carbon emissions trading or carbon tax, is necessary to achieve the ambitious carbon reduction target at the least cost in China.

Given the theoretical and cost advantages of emissions trading, the progress of emissions trading practice in China has been reviewed in this chapter. The best available data for carbon emissions trading in the context of China, SO_2 emissions trading practice, represented by Taiyuan case, has been introduced. However, as no literature examines the outcomes of the existing SO_2 emissions trading programs, whether the emissions trading programs have effectively helped China achieve SO_2 reductions remains unknown.

Regarding the carbon policy environment, China is a developing country with a semi-free market and relatively low public awareness of the environment. In addition, the dual leadership systems of local EPBs and the dual roles of local governments may cause difficulties in the enforcement of an emissions trading policy. China may lack the resources or ability to implement carbon emissions trading. It is therefore necessary to learn the lessons from the existing SO_2 emissions trading programs in China.

The next chapter will explain the methodology to be used in examining the outcomes of the existing SO_2 emissions trading programs in China. Findings and discussions will be presented as well, addressing research Q1: *Is emissions trading a suitable policy for achieving carbon reductions in China?*.

Chapter 4 Methodology

4.1 Introduction

The previous two chapters provided a review of the literature on which this research is based. The review revealed that in theory, an ETS is probably the best instrument to reduce carbon emissions, but whether it could be a suitable policy for China to achieve carbon reductions remains unknown, given that both the practice and empirical studies of emissions trading in China are limited. Research Q1 was thus formulated, *'Is emissions trading a suitable policy for achieving carbon reductions in China?'* (Chapter 2, section 2.5.3).

This chapter will provide an explanation and justification for the research methodology to be used in answering research Q1. It is organised as follows. The next section will present the overall research framework. Section 4.3 will discuss the case study approach for exploring the outcomes of emissions trading practice in China. The justification of using a case study approach, case study selection, methods of collecting data, data analysis and limitations of the case study approach will be included. Section 4.4 will explain the GHGs perspective interview used in this research to collect the experts' view on using emissions trading to achieve carbon reduction in China. It will give the information on how the interviewees were selected and interviewed and how the interview data were analysed. The reliability and validity of the case study and GHGs perspective interview will be discussed in section 4.5. Section 4.6 will present the ethical considerations for this research and section 4.7 will conclude the chapter.

4.2 Research framework

This research evaluates the policy proposal in relation to achieving carbon reductions in China. The whole evaluation is conducted in three steps (Figure 4.1):

1. Investigate the emissions trading practice in China by conducting a case study. Then compare the results from case study with the Theoretical Emissions Trading Response Model (Chapter 2, section 2.5.3) to identify the

gaps between the practice and the theory in the Chinese context to evaluate whether emissions trading is likely to be effective or not.

2. Conduct the GHG_S perspective interview to collect experts' views about implementing a carbon trading system in China. Discuss the results from both case study and GHG_S perspective interview to evaluate whether an ETS is suitable for China to achieve carbon reductions in the near future.

Then either

3. If an ETS is considered a suitable policy for reducing carbon emissions in China, a national carbon trading scheme would be proposed for China. The design features of an emission trading system that maximize carbon reductions in China will be discussed based on the experiences or lessons obtained from the literature, case study and GHG_S perspective interview.

or

3. If an ETS is found not suitable for China to achieve carbon reductions at this stage, an alternative policy instrument, carbon tax, would be investigated. A Chinese carbon tax CGE model will be constructed to model the effectiveness of a carbon tax in reducing carbon emissions as well as subsequent impacts on China's economy and energy consumption structure.

This three-step research design can address the research questions. The research Q1 (*Is emissions trading a suitable policy for achieving carbon reductions in China?*) is partly answered by conducting a case study and complemented by a GHG_S perspective interview. If the answer to the research Q1 was positive, the research Q2 (*What design features of a carbon trading system would maximize emission reductions in China?*) would be answered by the experiences or lessons gained from the literature, case study and GHG_S perspective interview. Otherwise, the research Q3 (*Is carbon tax a suitable policy for achieving carbon reductions in China?*) would be answered by using a Chinese carbon tax CGE model. As research Q2 and Q3 are mutually exclusive questions that depend on the answer to research Q1, the methodology for research Q1 is described first in this chapter. The carbon tax CGE model methodology will be presented after analysing the case study and GHG_S perspective interview data if the answer to the research Q1 is negative.

The selection of the appropriate method is based on determining the best way to address the research question. To answer the research Q1, a qualitative research approach is suggested for three reasons. First, the research question is primarily exploratory, in that little is known about the effectiveness of emissions trading instruments in China. Second, qualitative investigations are situation-oriented and can explore unexpected outcomes, which is quite appropriate in addressing the exploratory research questions (Stake 1995). Third, there is a lack of reliable quantitative data because there has been no real monitoring and evaluation of the trading schemes. However, the quantitative aspect is incorporated in this research design by including some ‘quantitative type’ questions through each semi-structured interview to assist the evaluation and interpretation of the results from the principal qualitative study. In summary, this research so far has used the principal research method of qualitative research, but with a little quantitative data considered.

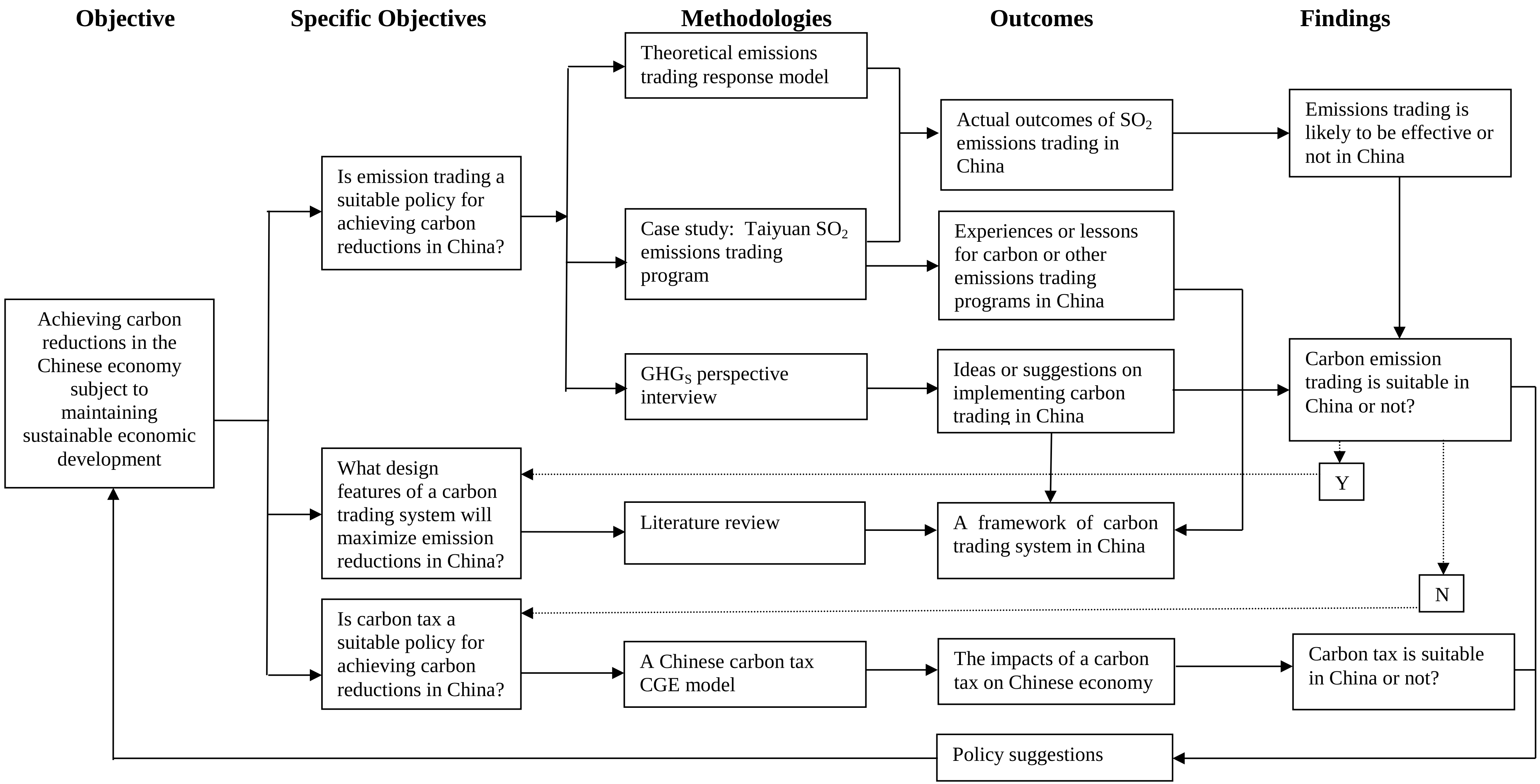


Figure 4.1 Research framework

4.3 Case study

4.3.1 Justification for using case study research

'A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident' (Yin 2009, p. 18). It is an intensive study of a single case for the purpose of shedding light on a population of cases (Gerring 2007). The researcher can benefit from flexibility in methods of data collection, particularly in the use of multiple sources of evidence (Stake 1995). The case study research method is preferred when research questions are 'how' or 'why', the researcher has little or no control on the events, or the phenomenon is contemporary within a real-life context (Yin 2009). In addition, a case study is especially suitable for learning about a situation where there is little background (Leedy & Ormrod 2009).

A case study method is adopted in this research for four primary reasons. First, emissions trading practice is a contemporary event in China and the researcher cannot manipulate the performance of the practice. Second, as noted earlier, there are few emissions trading practices in China and little literature has examined the implementation performance of these practices. Whether such emissions trading regimes actually work or not in China remains unanswered empirically. Third, a case study approach is considered one of the best ways of studying a policy (Purdon et al. 2001). Fourth, the research question requires an extensive and in-depth description of emissions trading practices in China. By using the case study method, the researcher has the ability to directly observe emissions trading practices and could conduct interviews with the people involved in the practices.

The case study in this research is a single case (Yin 2009), which is the SO_2 emissions trading program in Taiyuan city. The SO_2 emissions trading program is the only air pollutant emissions trading practice in China and the method of linking early SO_2 schemes into national carbon trading schemes has been justified earlier (Chapter 2, section 2.5.6). The reasons for selecting a single Taiyuan case will be presented in the next section. This case study is used to explore the effectiveness of emissions trading in the Chinese context, where experiences and lessons could be used to improve the existing emissions trading systems or designing a future carbon trading system in China. From the case study, the following information will be collected: (1) the impacts of the SO_2 emissions trading program on the participating companies; (2) the participants' and regulators' attitudes towards SO_2 emissions trading; (3) the problems of the existing SO_2 emissions trading program; and (4) suggestions for the future carbon emissions trading program, which could answer research Q1 (*Is emissions trading a suitable policy for achieving carbon reductions in China?*).

4.3.2 Case study selection

Case study research may be implemented through either a single case study or multiple case studies. Yin (2009) proposes that a single case study design is rational when the case represents (1) a critical case in testing an existing theory, (2) an extreme or unique case, (3) a representative or typical case, (4) a revelatory case or a (5) longitudinal case. A representative or typical case means that the case may represent a typical project among many different projects, from which the lessons learned are assumed to be informative about the experiences of the average situation (Yin 2009). Following Gerring (2007), a typical case approach is used for choosing the Taiyuan case in this research. As mentioned in literature review, seven regions have implemented SO_2 emissions trading in China (Chapter 2, section 2.5.2). Due to the potential risk that a case may turn out not to be the case it was thought to be, careful investigation of all the potential cases to avoid misrepresentation is required (Yin 2009).

Taiyuan city, the capital of Shanxi province, is a heavily industrialized area and one of the most polluted cities in China. Industry accounted for 43.7% of provincial GDP in 2009[18], which was largely based on coal mining, coke production, iron and steel industries, construction cement, chemical manufacturing and ceramics. In 2008 the annual average SO_2 concentration in Taiyuan is 0.073 mg/m^3, 11.5% more than the People's Republic of China's Class II annual standard (0.06 mg/m^3) (National Bureau of Statistics & Ministry of Environmental Protection 2009).

Taiyuan has always been the forerunner in air pollutants total quantity control and emissions trading practice in China. In 1990 Taiyuan was selected as one of the 16

[18] Statistical information of Taiyuan website, http://www.tytj.gov.cn/tongjijuWW/news/index.jsp.

pilot cities to implement an air pollutants emission permits system by the SEPA (Yang et al. 2003). In 1994 Taiyuan and five other cities first carried out the air pollutants emissions trading pilots. Taiyuan published the 'Administrative Regulation for Total Quantity Control of Air Pollutants Emissions in Taiyuan City' in 1998, which is the first local regulation on total quantity control of emissions in China. The 'Administrative Regulation for SO_2 Emissions Trading in Taiyuan City (Trial)' (Appendix 3) in 2002, representing the formal implementation of Taiyuan SO_2 emissions trading program, is also the first local regulation of SO_2 emissions trading in China.

Given that Taiyuan city has always been a heavily industrialized area and one of the most polluted cities in China, and a forerunner in air pollutants total quantity control and emissions trading practice, it is considered the most representative area among the seven regions involved in emissions trading practice in China. The Taiyuan SO_2 emissions trading program, as the oldest and most comprehensive emissions trading program in China, is thus considered a typical practice and its experience could illustrate the emissions trading situation in China.

4.3.3 Data collection for the case study

Six sources of evidence are mostly used in case studies: documentation, archival records, interviews, direct observations, participant observation and physical artefacts (Yin 2009). The use of multiple sources of evidence allows an investigator to address a broad range of historical, attitudinal and behavioural issues, and to develop converging lines of inquiry, thus making the findings or conclusions more convincing and accurate (Yin 2009). In the case study of the Taiyuan SO_2 emissions trading program, documentation and interviews were applied in the data collection. The data collection timeline period took place over three months from May to August 2010, which allowed for a comprehensive data collection to be carried out, in order to understand emissions trading in China.

A protocol was developed for preparing to collect evidence for the case study. The instruments, procedures and general rules to be followed were contained in the protocol (Yin 2009). It is an effective way of increasing the reliability of the case study and guiding the investigator in collecting data (Yin 2009). To collect useful data for the case study, the researcher was self-trained by learning related skills, especially interviewing skills.

4.3.3.1 Documentation

'For case study, the most important function of a document is to corroborate and augment evidence from other sources' (Yin 2009, p. 103). In addition, the documents can help researchers make reasonable inference (Yin 2009). This case study used a range of documents, including newspaper articles, administrative documents (proposals, progress reports and internal records), formal studies, community newsletter articles and so on. These documents are useful even though they are not always accurate and may be biased (Yin 2009).

The researcher first collected relevant information from the local newspapers, including *Taiyuan Daily* and *Taiyuan Commercial Daily*, the professional newspapers such as *China Environmental News* and *Environmental Protection* in the Taiyuan Library, and from the official websites of government departments such as the official websites of the Taiyuan EPB and Statistical Information of Taiyuan. The researcher learned more about the Taiyuan SO_2 emissions trading program from the documentation and then was able to select the target interviewees for this case study. The documentation collection went on throughout the data gathering period.

4.3.3.2 Interviews

An interview is one of the most essential sources for collecting data for a case study (Yin 2009). The first-hand data for this case study was obtained from interviews conducted with the managers responsible for SO_2 trading affairs in the participating companies, and the relevant administrators from the Taiyuan EPB. As an elaborated in-depth response was required in the case study, only a small number of people were involved and most of the questions were 'open' (i.e., they required the interviewer's insight and understanding) and the interviews adopted a semi-structured face-to-face format (Gillham 2000).

Selection of the interviewees

The Taiyuan EPB is the administrative department of the SO_2 emissions trading program in Taiyuan city. It was expected that administrators from this bureau, who had been in charge of the program, would have a comprehensive knowledge of the

SO_2 emissions trading practice. Three departments in the bureau, including the previous Atmosphere Department, the Development & Supervision Department, and the Pollutants Total Quantity Control Department, have been responsible for the program since it was implemented. Therefore, three administrators were selected as interviewees, one each of these departments. The fourth administrator interviewee is from the Taiyuan Environmental Research & Design Institute, which is an affiliated organization of the Taiyuan EPB. He was chosen as he not only participated in the establishment of the program, but he also followed up its progress.

According to the 'Administrative Regulation for SO_2 Emissions Trading in Taiyuan City (Trial)', all the units emitting SO_2 emissions in Taiyuan city are covered by the SO_2 emissions trading program. The documentation collected from the official website of the Taiyuan EPB showed that 105 enterprises were covered by the Taiyuan SO_2 emissions trading program in 2007, with a total of 62 365.3 t of SO_2 emissions permits. Based on the SO_2 emissions permits allocated in 2007, the top 45 emissions enterprises were selected as the target enterprises, and their emissions allowances accounted for more than 99% of the total for Taiyuan city in 2007. Therefore, the managers in charge of SO_2 trading affairs from each of these 45 enterprises respectively were considered for target interviewees. Table 4.1 summarizes the selection of the interviewees for the case study[19].

[19] It should be noted that since the interviewees have an inherent interest in the emissions trading, their opinions can be biased. The author will try to verify the interview results from the real data.

Table 4.1 Selection and response of the interviewees

Target Participants Groups	Number	Details		Selection Reasoning	Response Number
		Participants Source	Number		
Administrators	4	Previous Atmosphere Department	1	The administrative departments have been in charge of the Taiyuan SO_2 emissions trading program since it was implemented.	4
		Development & Supervision Department	1		
		Pollutants Total Quantity Control Department	1		
		Taiyuan EPB Environmental Research & Design Institute	1	Participated in the establishment of Taiyuan SO_2 emissions trading program, and follows up its progress.	
Enterprise Managers	45	The enterprises covered by the Taiyuan SO_2 emissions trading program	45	The top 45 enterprises of SO_2 emissions permits allocated in 2007.	20
Total	49		49		24

Interview questions

The interview questions for the enterprise managers included three themes: the basic situation of the company, the Taiyuan SO_2 emissions trading practice and the future carbon trading program (Table 4.2 and Appendix 4), while the administrators were only interviewed for the latter two themes (Table 4.3 and Appendix 5). Each theme was explored through several questions and sub-questions. Sub-questions differed slightly for the enterprise managers and administrators. It has been recommended by Yin (2009) that some case study interview questions be open-ended, allowing for the opportunity to ask respondents both facts and opinions about a specific event or matter. Most of the interview questions for this case study are open, though some provided guidance.

A full understanding of the Taiyuan SO_2 emissions trading practice is essential for this case study. Ideas on the future carbon trading could help in the discussion about using carbon trading policy or even building a national carbon trading scheme in China. Therefore, the overall structure of interviews was as follows. Initially, a number of background questions were asked, for example, each enterprise manager was asked about the basic situation of their company. Subsequently, two main themes, the Taiyuan SO_2 emissions trading practice and a future carbon trading program, were explored by asking six main questions. The interview questions investigating the first theme related to the performance of the Taiyuan SO_2 emissions trading program, attitudes towards Taiyuan SO_2 emissions trading and the problems of the existing Taiyuan SO_2 emissions trading program. The second theme was investigated by asking questions about the attitudes towards carbon trading, the experiences or lessons learned from SO_2 trading for carbon trading and the design features of a carbon trading scheme in China.

Specifically, as mentioned in the literature review (Chapter 2, section 2.5.3), the performance of an emissions trading program is normally evaluated by considering emissions reductions, cost effectiveness, innovation and investment in clean technology and leakages. So the performance of the Taiyuan SO_2 emissions trading program is examined from these aspects by asking four related sub-questions. Attitudes towards the program were explored through sub-questions about the effectiveness of the program, a comparison with command-and-control regulations and, only for administrators, the functioning of the emissions trading market.

Table 4.2 Interview questions: enterprise managers

Interview themes	Primary questions	Sub-question topics
Basic situation of the company	Brief introduction of the company	
	Company's experience on SO_2 emissions trading	
The Taiyuan SO_2 emissions trading practice	The performance of the Taiyuan SO_2 emissions trading program	• Emissions reductions • Emissions cost • Innovation and investment in clean energy • Investment outside Taiyuan (leakage)
	Attitudes towards the Taiyuan SO_2 emissions trading program	• Effectiveness of the program • Comparison with command-and-control regulations
	The problems of the existing Taiyuan SO_2 emissions trading program	
Future carbon trading program	Attitude to carbon trading	
	Experiences or lessons from the Taiyuan SO_2 emission trading practice that would be applicable for carbon trading	
	How to design the key features of future carbon trading scheme in China	

Table 4.3 Interview questions: administrators

Interview themes	Primary questions	Sub-question topics
The Taiyuan SO_2 emissions trading practice	The performance of the Taiyuan SO_2 emissions trading program	• Emissions reductions • Emissions cost • Innovation and investment in clean energy • Investment outside Taiyuan (leakage)
	Attitudes towards the Taiyuan SO_2 emissions trading program	• Effectiveness of the program • Comparison with command-and-control regulations • Functioning of the emissions trading market
	The problems of the existing Taiyuan SO_2 emissions trading program	
Future carbon trading program	Attitude to carbon trading	
	Experiences or lessons from the Taiyuan SO_2 emission trading practice that would be applicable for carbon trading	• Differences between SO_2 trading and carbon trading • Differences between Taiyuan and other regions in China
	How to design the key features of future carbon trading scheme in China	

Conducting interviews

To involve the target interviewees in this research, the researcher first found the contacts of the 49 target interviewees from the official websites of relevant departments or enterprises and then contacted them via email or by phone to check their willingness to participate. The purpose of this research, its relevance to the interviewees and the benefits of participation were explained to the target interviewees through a Plain Language Statement (Appendix 7). For those interested interviewees, an email was then sent outlining the specific details of the research, including an outline of the interview questions.

In the event, the four targeted administrators and 20 of the 45 enterprise managers agreed to be interviewed (Table 4.1). The 20 enterprises that responded account for more than 96% of the emissions permits allocated among the 45 target enterprises. It seems that large enterprises were more willing to participate in the research. The participating enterprises covered 11 industries, varying from firepower generation to beverage manufacturing and most of them were state-owned capitalized enterprises (Table 4.4). The SO_2 emissions were relatively concentrated in a few industries, with firepower generators the major polluting sources.

The 24 interviewees were asked to sign consent sheets with information on the time, place, participants, form, and content of the interviews (Appendix 8). They were interviewed in Chinese as most of them were lacking the necessary English skills. All the interviews were conducted at the offices of the interviewees. This arrangement was convenient for the interviewees, and allowed them to be comfortable and relaxed in an environment they knew and understood. Each interview lasted for 40–60 minutes. The researcher conducted all the interviews personally to enhance data reliability.

There is a debate about the desirability of recording interviews (Yin 2009). Recording certainly provides a more accurate reproduction of any information than any other methods, but it can make subjects uncomfortable (Yin 2009). Therefore, prior to the interviews the interviewees were asked whether recording was allowed. Notes were taken for the interviewees who declined to be recorded. A total of two interviews with administrators and seven interviews with enterprise managers were recorded with a digital voice recorder. During the interview sessions, the interviewees were asked to provide relevant unpublished and published documents that supported their answers to the interview questions.

4.3.4 Analysing the case study evidence

Data analysis of a case study has been defined by Yin (2003, p. 109) as 'examining, categorizing, tabulating, testing and otherwise recombining both quantitative and qualitative evidence to address the initial propositions of a study'. The general analytical strategy of this case study was to rely on theoretical propositions (Yin 2009), which helped to identify possible gaps between theory and practice in the Chinese context. Two specific techniques were used to analyse the evidence collected. First, pattern matching was used to compare an observed emissions trading practice with a theoretical one (Trochim 1989). Second, explanation building was employed to analyse the case data by building an explanation about the Taiyuan SO_2 emissions trading case (Yin 2009). The qualitative data of this case study were analysed in three steps as outlined by Miles and Huberman (1994): data reduction, data display and conclusion drawing, and verification. Data reduction was conducted by summarizing the responses from the interviewees along the major themes that emerged from the data.

‘Content analysis is a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of theirs use’ (Krippendorff 2004, p. 18). It was applied to analyse the interviews of this case study (Marshall & Rossman 1995). This examined how respondents viewed and understood certain issues (Trace 2001). The key substantive statements of the interviewees were identified and then put in categories according to the main interview questions, which were derived from the literature on emissions trading theory. No computer analysis was undertaken as the resulting data could be managed with direct analysis and categorisation. Verbal transcription was not employed in analysing the interview data because it is time consuming, provides a lot of disconnected statements and the researcher has to reconsider the value of the ‘redundant’ material (Gillham 2000).

For each interview, a report was developed based on the interview questions. The summarized interview reports were sent to each interviewee to obtain feedback and to allow the interviewees to make any changes they deemed necessary. Finally, a case study database was developed, including case study notes made by the researcher after some interviews, case study documents, tabular materials and case study interviews. To ensure the confidentiality of the interviewees, all the interviewees were coded and all data were reported in a de-identified form (Lincoln & Guba 1985; Patton 2002). The 20 enterprises were coded according to the emissions permits allocation in 2007 from largest to smallest (i.e., EN1 to EN20). Similarly, the 20 enterprise managers were coded MA1 to MA20. Appendix 9 shows the profile of the coded enterprises and coded managers. The four administrators from the Taiyuan EPB were coded AD1 to AD4.

4.3.5 Limitations of the case study research

Some literature has outlined major concerns with the case research method (Parkhe 1993; Yin 2009), including (1) a lack of rigor, (2) providing little basis for scientific generalization, (3) overlying complex theories, (4) investigator bias, (5) lack of self-sufficiency and a potential to produce a well-founded theory that maximizes the research quality of validity and reliability at the same time, (6) gaining access to the organizations (i.e., organization access in this research required negotiating with enterprise managers and administrators) and (7) limitations in the geographical area (i.e., this research was conducted in a regional area). These limitations of the case study method were taken into consideration in this research.

Strong measures had been taken to build rigor into this case study at the research design, data collection, data analysis and composition stages (Table 4.6). Due to the limitations in the geographical area, the researcher was very cautious about generalizing conclusions from the Taiyuan case. In addition, the limitation of research quality criteria in terms of validity and reliability are addressed in section 4.5.

However, this case study research still had a few limitations:

1. There was a limitation on the sample size: the relatively small number of interviewees. But the Taiyuan SO_2 emissions trading program itself is a local program with limited companies and experienced people. Therefore, the sample size in this case study is considered sufficient to examine the outcomes of the practice.
2. The selection of target enterprises based on the permits allocation data of 2007. Some people may argue that the possible changes in 2008 and 2009 have not been considered. However, the 2007 permits allocation data were the latest data available from the documents when choosing the target enterprises. After conducting the interviews, it was found that the interviewed 20 participant enterprises were still in the top 45 places of permits allocation in 2009.
3. Due to time restrictions, the interview time for some interviewees was short. Despite this, the researcher had asked all the interview questions and collected all the related information.
4. Due to the limited record kept in the participating enterprises, the researcher obtained little quantitative data to support the qualitative information and had to rely on the interviewees' recollections. Though the qualitative data is not as accurate as quantitative data, it is still reliable enough to make the evaluation.

4.4 GHGs perspective interview

Another GHG_S perspective interview was conducted in this research to collect experts' views on the implementation of a carbon trading system in China. Given the small sample and all of the interview questions being 'open', this interview was a face-to-face semi-structured in-depth interview. Generally, an in-depth interview refers to an unstructured or semi-structured, direct, personal interview in which a single participant is probed by an interviewer to explore underlying motives, beliefs, attitudes and/or feelings about a topic (Malhotra & Birks 2007).

4.4.1 Interviewee selection

In regards to the sampling of the in-depth interviewees, judgmental sampling was considered to be the most appropriate technique for this GHGs perspective interview. It refers to a sampling technique in which interviewees are selected based on the judgement of the researcher (Malhotra & Birks 2007). In particular, certain individuals are selected because the researcher believes that they are suitable for addressing the issues (Patton 2002). Judgmental sampling was adopted in this research as it enabled the researcher to select the experts who were 'eligible' to discuss the carbon reductions and carbon trading issues in China. In this research, eligibility refers to the practical experts, theoretical experts in the emissions trading area and policymakers on carbon reductions issue.

The Tianjin Emissions Exchange, the Shanghai Environment & Energy Exchange and the Beijing Environment Exchange are the largest and oldest emissions exchanges in China so far. It is believed that these emissions exchanges have abundant experience in carrying out the emissions trading practice in China. Managers from these three emissions exchanges were chosen as target interviewees because they were considered practical experts in emissions trading area in China. Their views on using carbon trading to reduce carbon emissions in China would be very insightful. Another three theoretical experts were selected based on the literature of emissions trading in China. They have published articles on emissions trading and are famous in this area. It is expected that their views on using emissions trading to achieve carbon reductions in China would be meaningful. Notably, one expert from the Environmental Planning Institute of the Chinese Research Academy of Environmental Science, who is a pioneer in the research of environmental policy in China, also participated in designing the Taiyuan SO_2 emissions trading program in 2002.

In addition, policymakers were interviewed to collect the political views on the implementation of carbon trading policy in China. The NDRC and the Ministry of Environmental Protection of the People's Republic of China are the two main departments in deciding environmental policy in China. Therefore, two policymakers from each of the two departments were selected as target interviewees. The selection of all the target expert interviewees is detailed in Table 4.4.

Table 4.4 Experts selection and response

Target Participants Groups	**Details**		**Selection Basis**	**Response Number**
	Participants Source	**Number**		
Practical experts	Tianjin Emissions Exchanges	1	Extensive practical experience in carrying out emissions trading in China.	1
	Shanghai Environment and Energy Exchanges	1		1
	Beijing Environmental Exchanges	1		1
Theoretical experts	Scholars on emissions trading	3	Well known scholars with publishing track record.	2
Policy-makers	Resource Conservation and Environmental Protection Division of NDRC.	1	They have great influence on making environmental policy and can analyse the using of carbon trading policy in China from a political perspective.	0
	Ministry of Environmental Protection of the People's Republic of China	1		1
Total		8		6

4.4.2 Interview questions

The same interview questions were used for all three kinds of expert interviewees to make the answers relatively comparable. In order to answer the research Q1 (*Is emissions trading a suitable policy for achieving carbon reductions in China?*), the interview questions in this GHGs perspective interview were designed to elicit experts' attitudes and ideas towards using an emissions trading instrument to achieve carbon reductions in China. Details of the overall interview structure are in

Appendix 6. First, three general questions were asked to collect the information about the interviewees. Then, three main themes were explored through three open questions on the attitudes towards using carbon trading in China, the necessary considerations of using carbon trading in China, and the desirable design features of a Chinese carbon trading scheme. In particular, based on the literature, the sub-questions for investigating the second theme considered the market conditions, the level of economic development, the legal base and enforcement, and the differences between the EU and China.

4.4.3 Data collection and data analysis

The researcher used the same methods as in the case study interviews to contact the interviewees, to conduct the interviews, and to analyse and interpret the interview data. One theoretical expert was not available for an interview and one policymaker was not allowed to provide personal interviews. Three practical experts, two theoretical experts and one policymaker from the Ministry of Environmental Protection of the People's Republic of China were interviewed (Table 4.5). An interview protocol was established to enable the researcher to follow a consistent inquiry process and a consistent analysis procedure for these six interviews. The six interviewees were also anonymous in the process (coded as EX1 to EX6).

4.5 Reliability and validity in qualitative research

Validity refers to the 'correctness or credibility of a description, conclusion, explanation, interpretation, or other sort of account' (Maxwell 2005, p. 116). Maxwell (2005) identifies two key threats to the validity of qualitative research: researcher bias and reactivity. Researcher bias is due to the subjectivity of the researcher and could be tested by examining the extent to which the researcher is open to contrary results (Yin 2009). Reactivity is similar to bias in that it is related to 'the influence of the researcher on the setting or individuals studied' (Maxwell 2005, p. 118). The influence of the researcher in this qualitative study was impossible to eliminate, but the influence has been understood and used productively in the analysis of the study's findings (Maxwell 2005). In addition, the researcher was sensitive and responsive to the contradictory evidence in the case study (Yin 2009).

In assessing the quality of research design, Yin (2009) proposes four criteria for researchers to consider: construct validity, internal validity, external validity and reliability. The four criteria have been commonly used in empirical social research, including case study research (Kidder et al. 1986; Yin 2009). The application of these criteria in the case study has been presented in Table 4.5, which shows how the four criteria were addressed to improve the rigor.

Table 4.5 Case study tactics for four design tests

Tests	Test explanation	Case study tactics	Phase of research in which tactic occurs	Application within the Taiyuan study
Construct validity	Identifying correct operational measures for the concepts being studied	• Use multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report	Data collection Data collection Composition	• Both documents and interview were used in collecting case study evidence. • The summarized interview reports were sent to each interviewee to obtain feedback and to allow the interviewees to make any changes they deemed necessary.
Internal validity	(For exploratory studies) Indicating the inferences made on the basis of interview and documentary evidence are correct.	• Do pattern matching • Do explanation building • Address rival explanations • Use logical models	Data analysis Data analysis Data analysis Data analysis	• Did pattern matching. The results of the case study were compared with the Theoretical Emissions Trading Response Model to identify the gaps between theory and practice in China. • Did explanation building. The reasons of inactive emissions trading market are explored and explained.
External validity	Defining the domain to which a study's findings can be generalized.	• Use theory in single-case studies • Use replication logic in multiple-case studies	Research design Research design	• A typical case approach was used for choosing the Taiyuan case. • The literature review on lessons from early schemes into national carbon trading scheme.
Reliability	Demonstrating that the operations of a study – such as the data collection procedures – can be repeated, with the same result.	• Use case study protocol • Develop case study database	Data collection Data collection	• A case study protocol was developed before collecting evidence for case study. • Provided detailed descriptions of the participants, of the context in which the research was carried out. • At least some interview data that was mechanically recorded (audio). • During the interviews, the interviewees were asked to provide relevant documents to support their answers to the interview questions. • A case study database was developed, including case study notes made by the researcher after some interviews, case study documents, tabular materials and case study interviews.

Source: developed from Yin (2009, p. 41)

4.6 Ethical considerations

The principal ethical consideration in this research is the engagement of the interviewees. Ethics clearance to conduct this research was obtained from the University of Southern Queensland (USQ) prior to the data collection. The confirmation from the USQ Human Research Ethics Committee is in Appendix 10. This research obeyed the following ethical guidelines:

1. The nature and purpose of this research project was explained to the interviewees clearly (Lincoln & Guba 1985);
2. Participation was entirely voluntary. A sign-off consent form was obtained from the interviewees before conducting interviews (Lincoln & Guba 1985; Patton 2002);
3. The interviewees could withdraw from the research at any time without any fear of consequences;
4. The interviewees were coded and all data was reported in a de-identified form to ensure confidentiality (Lincoln & Guba 1985; Patton 2002); and
5. The contact details of the researcher were given to the interviewees in case that they had further questions regarding the research (Lincoln & Guba 1985).

4.7 Conclusion

This chapter has provided the methodology used in answering research Q1 (*Is emissions trading a suitable policy for achieving carbon reductions in China?*). The research methods involved a case study and a GHG_S perspective interview. Both of these approaches have been carefully justified and described. The next chapter will present the results and interpretations of the case study and the GHG_S perspective interview. The findings will answer research Q1 and decide the next research question, either Q2 (*What design features of a carbon trading system would maximize emission reductions in China?)* or Q3 (*Is carbon tax a suitable policy for achieving carbon reductions in China?*).

Chapter 5 Analysis and discussion of the case study and interview results

5.1 Introduction

Chapter 4 described the overall research framework and explained the research methodologies used in this research, which included a case study for the Taiyuan SO_2 emissions trading and expert interviews for the carbon emissions trading, to address research Q1 (*Is emissions trading a suitable policy for achieving carbon reductions in China?*). This chapter will first present the findings from the case study and the GHGs perspective interview, and then discuss the suitability of using emissions trading to achieve carbon reductions in China, the results of which will address research Q1 of this study.

This chapter is structured as follows. Section 5.2 will present the outcomes of the Taiyuan SO_2 emissions trading program, including its performance, participants' attitudes and its limitations. The views on using an ETS to achieve carbon reductions in China will be summarized in section 5.3. Section 5.4 will discuss the findings from the case study and the GHGs perspective interview.

5.2 Results for the case study

This section provides a detailed picture of the Taiyuan SO_2 emissions trading practice. Twenty managers and four administrators participated in the interviews. The presentation of the results of the interviews follows the sequence of the main interview questions asked: the performance of the Taiyuan SO_2 emissions trading program, attitudes towards the Taiyuan SO_2 emissions trading program, and the limitations of the existing Taiyuan SO_2 emissions trading program. Specifically, the reasons behind the inactive SO_2 emissions trading market in Taiyuan are further explored and presented. Some interview results are supported by data from the available documents.

5.2.1 The performance of the Taiyuan SO_2 emissions trading program

The performance of the Taiyuan SO_2 emissions trading program are examined in relation to four impacts. They are the level of emissions, emissions cost, innovation or investment in clean technology and investment leakage, which have been justified in Chapter 2 and further explained in Chapter 4. The results are summarized in Table 5.1, with 'Yes', 'No', 'I do not know' and 'Refuse to answer' being the interviewees' overall answers to the question. As can be seen, both the managers and the administrators showed relatively consistent views on three of the four performance indicators but not on the emissions costs. Namely, most of the respondents agreed that the Taiyuan SO_2 emissions trading program reduced emissions, promoted the innovation or investment in clean technology and did not lead to leakage outside Taiyuan city, but it did not obviously reduce the emissions costs.

Table 5.1 The performance of the Taiyuan SO_2 emissions trading program

Questions	Interviewees	Yes	No	I do not know	Refuse to answer
Reduce emissions	20MA, 4AD	20MA, 4AD	0	0	0
Reduce emissions cost	20MA, 4AD	3MA	6MA (1 raise), 1AD	9MA, 3AD	2MA
Innovation or investment in clean technology	20MA, 4AD	18MA, 3AD	1MA	0MA, 1AD	1MA
Direct and indirect investment out of Taiyuan city	20MA, 4AD	2MA	15MA, 2AD	1MA, 2AD	2MA

AD: Administrators; MA: Managers
Reduce emissions cost: compared with previous command-and-control regulations

All the interviewees agreed that there was a reduction in SO_2 emissions after the SO_2 emissions trading program was implemented. AD2 said that 'the SO_2 emissions of Taiyuan city reduced by 8000 t and about 4500 t in 2008 and 2009 respectively, and the SO_2 reductions were nearly 2000 t only in the first half year of 2010'. This point is supported by the data collected from the documents as well (Table 5.2). The total SO_2 emissions in Taiyuan decreased steadily since the SO_2 emissions trading program was introduced in 2003. The managers also indicated that they really reduced the SO_2 emissions of their companies because of the caps imposed by the government, rather than the trading.

Table 5.2 Taiyuan SO_2 emissions, 2001–09

Year	Total SO_2 Emissions (t)	SO_2 Emissions Reductions (t)	Annual Concentration of SO_2 (mg/m^3)	Number of Days the Air Quality Achieving or Better than Level 2[20]
2001	–	–	0.153	120
2002	232181	–	0.129	153
2003	234104	-1923	0.099	181
2004	217912	16192	0.087	224
2005	184503	33409	0.077	245
2006	160303	24200	0.08	261
2007	141399	18904	0.076	269
2008	133387	8012	0.073	303
2009	128787	4600	–	296

Note: The annual concentration of SO_2 for Taiyuan was 0.200mg/m^3 in 2000.
Data source: <China Environment Statistical Yearbook> from 2000 to 2009, and <Taiyuan Economic and Social Development Statistical Official Report> from 2001 to 2009.

Most interviewees, 86% of the managers and 75% of the administrators, said that the SO_2 emissions trading program helped the companies innovate or invest in clean technology. MA6 disclosed that his company spent around US$1.5 million on desulphurization equipment for reducing the SO_2 emissions in 2009. AD3 said that 'the limited and decreasing permits year by year force the companies to adopt advanced desulfurization equipment to reduce emissions'. Interestingly, 12 managers mentioned that their companies invested in clean technology simply to comply with the caps to 'ensure the company's reputation'. They actually did not evaluate the emission costs of different compliance strategies when choosing the compliance method. MA17 revealed that his company controlled the SO_2 emissions through improving the production process rather than employing new desulphurization technology.

Also, most interviewees suggested that the SO_2 emissions trading program did not lead to leakage. 75% of managers stated that their companies did not invest outside Taiyuan city because of the constraints from the SO_2 emissions trading program and would not do this in the future either. But MA11 said that his company 'transferred

20 According to the 'Environment Air Quality Standards': National Level 2 Standards (SO_2 0.060 mg/m^3) and National Level 3 Standards (SO_2 0.100 mg/m^3).

part of the business to other cities where there were no strict caps on the SO_2 emissions' and MA17 said that his company had the same intention. Those enterprises that had no intention of shifting investment were all large state-owned enterprises, which heavily relied on the raw materials in Taiyuan city or had to provide the necessary products, such as electricity, for the people living in Taiyuan city. The two with some intention of shifting investment were comparatively small companies engaged in concrete manufacturing and beverage manufacturing industries, which were considered more flexible in facing the challenges of the outside world.

As to whether or not the SO_2 emissions trading program achieved cost savings, the views varied a lot. Only three managers believed that the SO_2 emissions trading program did decrease the emissions cost, while 29% of interviewees thought it did not and half the interviewees said that they were unsure about this. MA13 even argued that 'the SO_2 emissions trading program forces the company to adopt desulfurization equipment, which in turn increases the emissions cost of the company' (Table 5.1). MA5, who was unsure about the changes of the emissions cost, explained:

> The average removal cost of per unit SO_2, including equipment depreciation, maintenance and operation fees, is mainly related to the sulphur content of coal and the generating capacity size. The average removal cost of per unit SO_2 is positively correlated with the sulphur content of coal and negatively correlated with the generating capacity size. So the SO_2 emissions cost varies a lot even in the same company during different periods. Even though there is a reduction in the SO_2 emissions cost, it cannot be simply attributed to the SO_2 emissions trading program.

In summary, SO_2 emissions in Taiyuan city have been effectively reduced after the SO_2 emissions trading program was implemented. In addition, the innovation or investment in clean technology has improved and little investment has been transferred out of Taiyuan city. But the answer was not clear as to whether the emissions cost had been reduced. Moreover, some innovation or investment in clean technology was simply motivated by the aim of compliance rather than being chosen as the most cost-effective compliance method. Little investment leakage may have been because many of the large businesses were necessarily tied to the city.

5.2.2 Attitudes towards the Taiyuan SO_2 emissions trading program

When the managers and administrators were asked about their overall attitudes towards the Taiyuan SO_2 emissions trading program, including the effectiveness of the program in reducing SO_2 emissions, a comparison with command-and-control regulations and the functioning of the SO_2 emissions trading market, they expressed relatively similar opinions. The summarized results have been shown in Table 5.3. As for the effectiveness of the Taiyuan SO_2 emissions trading program, both managers and administrators agreed that it was effective in reducing the SO_2 emissions. AD2 pointed out that 'the SO_2 emissions have been reduced significantly and the air quality has been improved greatly in Taiyuan city since the SO_2 emissions trading program was carried out'. This point can be supported by the data in Table 5.2.

Table 5.3 The overall attitude towards Taiyuan SO_2 emissions trading program

Questions	Interviewees	Yes	No	I do not know	Refuse to answer
Is it effective in reducing the SO_2 emissions?	20MA, 4AD	20MA, 4AD	0	0	0
Is it better than the previous command-and-control regulations?	20MA,4AD	9MA,4AD	6MA	2MA	3MA
Does the SO_2 trading market really exist?	4AD	0	3AD	0	1AD

AD: Administrators; MA: Managers

54% of interviewees, including 45% of managers and all the administrators, believed that the SO_2 trading program was better than the previous command-and-control regulations because it was much more effective in controlling and reducing the SO_2 emissions. In addition, AD3 revealed that:

> the SO_2 emissions trading program saves the administration cost of mitigating SO_2 emissions. Unlike command-and-control regulations, it does not need the administrators to visit the companies from time to time to check their compliance.

However, six managers expressed the opposite view. MA7 said that:

> even though I know the company should take the social responsibility to protect the environment and achieve sustainable development, I still oppose the SO_2 emissions

> trading program as it constrains the development and decreases the interest of the company.

Only the four administrators were interviewed about the functioning of the SO_2 emissions trading market in Taiyuan. None of the administrators thought the Taiyuan SO_2 trading market had developed properly so far. AD4 said that 'the SO_2 emissions trading market is very poor and it actually cannot be called a market'. AD2 gave the details of existing situation of the Taiyuan SO_2 trading market:

> except for two simulant trades in December 2002 when the program was initially piloted, there had been only 19 transactions until July 2009, involving 807 t of emissions. And 18 of them happened between newly built enterprises or projects and the old enterprises. The other trading, which was also the first SO_2 emissions trading case, took place between enterprises in 2003.

In summary, it appears that the Taiyuan SO_2 emissions trading program was effective in term of reducing SO_2 emissions. Due to its effectiveness in reducing emissions and the capability of savings administration cost, most of the respondents believed the SO_2 emissions trading program was better than the previous command-and-control regulations. However, it is generally agreed that an operational SO_2 emissions trading market in Taiyuan had not been formed.

5.2.3 Perceptions of the limitations of the Taiyuan SO_2 emissions trading program

Twelve major limitations of the existing Taiyuan SO_2 emissions trading program have been summarized from the interview data: the legal basis, character of the emissions trading system, allocation method, allocation policy, linkage policy, monitoring, tracking and management system, responsible department or person, trading information, administrative enforcement, administrative intervention and emissions trading market (Table 5.4).

Table 5.4 The limitations of the Taiyuan SO_2 emissions trading program

Interviewees	Limitations of the Taiyuan SO_2 emissions trading program
AD2, AD4	The legal basis was not strong enough.
AD2	The design of the program was half an emissions trading system and half a fee system.
MA3, MA12	The emissions allowances allocation method was unfair.
MA1, MA3, MA8, MA15	The allocation policy was unpredictable.
MA2	The linkage policy was unreasonable.
AD4	The continuous online monitoring equipment was too limited.
AD3	There was no electronic SO_2 emissions allowances tracking system and transactions management system.
AD4	There was no fixed department or person responsible for the program.
MA1, MA2, MA7, MA14, MA18	The information of SO_2 emissions trading was not open and transparent.
AD1	The administrative department did not attach importance to the program.
MA3	The administrative intervention in the program was too strong.
AD1, AD2, AD3, AD4	The emissions trading market had not yet been formed.

AD: Administrator; MA: Manager

Both AD2 and AD4 argued that the legal basis of the Taiyuan SO_2 emissions trading program was not strong enough. AD4 explained that:

> the program is established on the basis of 'Administrative Regulation for SO_2 Emissions Trading in Taiyuan City', which is a local administrative regulation published by the people's government of Taiyuan city in 2002. While at the national level, there is no specific law or regulation for emissions trading. The most relevant laws are 'The People's Republic of China Environmental Protection Law' and 'The People's Republic of China Air Pollution Control Act'. But both of them are too generous for regulating SO_2 emissions trading in China.

The weak legal basis of the Taiyuan SO_2 trading program led to uncertainty and weak enforcement of the trading program.

AD2 pointed out that 'the design of the Taiyuan SO_2 emissions trading program is half an emissions trading system and half a fee system'. There was a cap in the SO_2 emission trading system and the overall cap was going down year by year, but the implementation currently focused on the compensation for using the emission rights. The emissions permits were not provided for the emissions enterprises for free, nor were they sold by auction. In practice, the Taiyuan EPB charged the enterprises RMB¥0.2/kg on the actual SO_2 emissions quarterly. AD2 further said that 'this different design makes the enterprises' managers and even some administrators misunderstand what a real emissions trading program should be like'.

MA12 said that 'the emission allowances allocation method is unfair as it is based on the historical emissions data of the enterprises, ignoring other factors, such as production, fuel efficiency'. The most polluting enterprises received the most allowances. MA3 also expressed a similar view on this limitation. MA3 said that:

> the production in our company increased rapidly in recent years. But the yearly decreasing emissions permits, which are only based on the historical amount of emissions rather than considering the recent amount production, exert an increasing pressure on the company of surrendering enough emissions permits. I think this is unfair for our company. Actually, the SO_2 emission factor in our company is much smaller than that in other companies.

The total quantity allocation policy was criticized as too difficult to anticipate. Four managers said the outcomes from the total quantity allocation policy were unpredictable. MA15 explained that 'even though the initial allocations cover five years, the allowable emissions may suddenly decrease as the emissions control from the higher levels of government gets stricter'. MA3 complained that:

> the introduction of new equipment is easier to say than do. It normally takes at least one year to make the plan, prepare the budget and choose the suppliers. However, the suddenly tightened emissions allowances could make us at a loss. According to one old Chinese saying, this is called a plan that cannot keep up with a change.

MA8 said that insecure emissions permits made it difficult for them to make plans so they preferred to keep the extra emissions permits in hand rather than sell them in the trading market.

The linkage policy was also criticized by MA2 as unreasonable. MA2 said that:

> a newly built enterprise or project, which emits SO_2 emissions, must get the SO_2 emission allowances before being put into operation. But the current linkage policy for the newly built enterprises or projects is limited to buying allowances from the existing enterprises, without auctioning. They need to wait for the next Five-Year Plan to participate in the initial allowances allocation as the SO_2 emission allowances are allocated in the first year of the Five-Year's Plan.

Meanwhile, the deficient trading information and the inactive trading market made it difficult for new enterprises or projects to get the allowances from the emissions trading market.

AD4 argued that 'the total amount of emissions may be underestimated in the Taiyuan SO_2 emissions trading program' as only a few large and key SO_2 emitters had installed the continuously online monitoring equipment due to the expense and its high maintenance cost. Most of the enterprises used materials balance calculations to measure their emissions and declared the emissions data on an annual basis (a self-reporting mechanism). AD4 further disclosed that ‘the emissions data may not be reliable as well’ because the continuous online monitoring equipment had not been checked since it was installed, and some might have been damaged and could not measure the emissions correctly.

AD3 revealed that ‘there is no electronic SO_2 emission allowances tracking system and transactions management system in the Taiyuan SO_2 emissions trading program’. Both the information of emission allowances allocation and transactions were registered separately by the Taiyuan EPB. Thus the related trading information could not be provided in a timely and accurate way.

AD4 pointed out that ‘no specified department or personnel from Taiyuan EPB is responsible for the Taiyuan SO_2 emissions trading program’. Due to departmental and personnel changes, three departments (the previous Atmosphere Department, the Development & Supervision Department, and the Pollutants Total Quantity Control Department) and several administrators in the Taiyuan EPB had been in charge of the program since it was implemented in 2003. Many valuable original documents and data were lost due to the frequent work transitions from one person to another and from one department to another.

Five managers mentioned that information on SO_2 emissions trading was not open and transparent. M14 said that:

> it promises in the ‘Administrative Regulation for SO_2 Emissions Trading in Taiyuan City’ that last year’s ‘Taiyuan SO_2 emissions and emissions trading bulletin’ and other related information are made available to the public in March each year. But actually, only a little of the information is published discontinuously.

MA7 complained that ‘except our own company, we do not know the SO_2 emissions situation of other companies, such as how many permits they were allocated and do they have any extra permits for trading?’. It was argued by MA18 that the efficiency of markets would increase with the free flow of information.

It was also suggested that the administrative department did not attach importance to this program. AD1 said that:

> the SO_2 emissions trading program was promoted by the ex-director of the Taiyuan EPB who thought highly of emissions trading. So it worked when he was in power, but this program was forgotten by the officers soon after a new director, who does not pay attention to this program, came into the office.

AD1 further revealed that it was common in Chinese administrative departments that the officer intends to do the things his superiors like or pay attention to. And only the things that the leaders attach great importance would be done well.

MA3 said that 'the Taiyuan EPB plays too much administrative intervention in the transaction process'. Though few emissions trades had been done, almost all the trading cases were matched by the Taiyuan EPB and the trading price was also suggested by the EPB. MA3 believed that it was necessary for the administrative department to intervene at the beginning of the program but that it should find 'a good balance between intervention and supervision' and act as a supervisor and let the program work by itself gradually.

As a few trades have taken place, the emissions trading market, as argued by all the administrators, has not yet developed properly. This finding was acknowledged in section 5.2.2. AD2 said that 'emissions trading has faded out of people's sight, people mention 'emissions reduction task' instead of 'emissions trading' when talking about sulphur dioxide'. As an emissions market is the most important part of a trading program, and could be used to evaluate the success of an emissions trading practice, the reasons why only a few trades have taken place so far were explored and listed below.

5.2.4 Reasons behind the inactive Taiyuan SO_2 emissions trading market

Given the importance of an emissions trading market in an emissions trading program, the reasons behind the limited Taiyuan SO_2 emissions trading market were further explored. As shown in Table 5.5, ten reasons have been identified. These can be classified in three categories: defective design, weak implementation and weak market structures.

Table 5.5 The reasons behind the poor Taiyuan SO_2 emissions trading market

Interviewees	The reasons for a poor emissions trading market	
MA8	Insecure emissions rights	Defective design
MA2	Unreasonable linkage policy	
MA7, MA14	Asymmetric information	Weak implementation
AD1	The government administrative department lacked the enthusiasm for regulating the emissions trading market.	
AD3	There is no emissions exchange.	Weak market structures
AD3, AD4, MA10	Most enterprises did not fully understand emissions trading.	
MA9	The alternative methods for complying with the caps were effective.	
AD2, MA16	It was difficult to reach an agreement on the emissions trading price.	
AD2	There were not enough participants in the program.	

AD: Administrators; MA: Managers

It was mentioned by some interviewees that some of the design and administrative implementation problems of the Taiyuan SO_2 emissions trading program also led to the inactive SO_2 emissions trading. The insecure emissions rights mentioned by MA8 and the current unreasonable linkage policy criticized by MA2 made the enterprises reluctant to participate in the emissions trading market. Furthermore, both buyers and sellers were reluctant to trade because of asymmetric information. MA7 said that:

> buying the allowances from the market is really difficult because neither the enterprises that have surplus SO_2 emissions allowances, nor the administrative department announces the allowances selling information publicly.

However, MA14 disclosed that his enterprise failed to sell extra allowances in some years because no buyers could be found. MA12 further explained that 'it is not worth spending too much time and effort in finding the buyers as the allowances revenue is relatively small to the enterprises'. In addition, according to AD1, the government administration lacked the enthusiasm for regulating the emissions trading market.

AD3 thought the most important reason why there had been only a few trades so far was that there was no emissions exchange in Taiyuan city. AD3 said that it was not appropriate for the Taiyuan EPB, as the administrative department of the Taiyuan SO_2 trading program, to be involved in trading activities. Besides, it lacked the enthusiasm to help promote trading. But 'the trading would get much better if there was an emissions exchange in Taiyuan city', which could act as an independent reliable third party, organizing the trading and releasing the allowances information.

Most enterprise managers still did not fully understand emissions trading. MA10 said that he knew ‘there is an allowable emission amount for the enterprise every year and the enterprise has to control the emissions under this prohibitive amount strictly’, but he had ‘no idea about emissions trading’. At the same time, AD3 complained that most of the large SO_2 emission units were old state-owned enterprises, with a workforce of a high average age and lacking the necessary skills. Based on the requirements of the program, the RFF and the Taiyuan EPB jointly organized more than 20 SO_2 emission trading training or seminars for 23 large and key SO_2 emissions enterprises at the beginning and mid-term of the program, but only a few of these participants really understood what emission trading was. AD4 also argued that ‘the enterprises do not know the benefits that they can obtain from emissions trading, and no emissions trading expert can be found in the Taiyuan EPB’.

MA9 said that his enterprises considered ‘investing in the desulphurization equipment as the first choice when short of emission allowances, because it is much more convenient and the machine can work immediately’. As one of the methods for complying with the caps, the desulphurization technology was quite mature so that the enterprises prefer investing in desulphurization equipment rather than permits trading, ignoring the fact that trading might result in lower cost.

AD2 disclosed that ‘some trading failed because the trading parties could not reach an agreement on the price’. MA16 said that ‘it is difficult to reach an agreement on the emissions trading price as there is no price for reference, neither recent trading nor guidance price’. They were afraid of suffering ‘losses’ and thus were cautious about trading. AD2 also emphasized the need of a guidance price for SO_2 emissions allowance, but determining a guidance price turned out to be a very complex subject. AD2 called for the research in this area in China.

Last but not least, AD2 argued that ‘there are not enough participants in the Taiyuan SO_2 emissions trading program’. AD2 explained that the Taiyuan SO_2 emissions trading program was a local emissions trading program with only about 10 key emission sources, so the participants of the emissions trading market were considered too limited, which also meant that it would be difficult to achieve cost savings. AD2 further suggested that 'the program would be much more successful if it were carried out at the provincial level or national level'.

5.3 Prospects for carbon emissions trading

5.3.1 Using emissions trading to achieve carbon reductions in China

The 20 enterprise managers, four administrators and six experts were asked for their opinions on using emissions trading to achieve carbon reductions in China. Their overall attitude has been summarized and presented in Table 5.6. As can be seen, only 7% of interviewees supported using emissions trading to achieve carbon reductions in China, while the same percentage were strongly against it. Though 27% of interviewees showed a comparatively optimistic attitude toward carbon trading, 17% of interviewees thought it was difficult to reduce carbon emissions through a carbon trading scheme and 43% of interviewees stated that it was hard to say or they had no idea about this question.

Table 5.6 Opinions on using emissions trading to achieve carbon reduction in China

Interviewees	Against	Difficult	Do not know or unsure	Possible	Support
20 managers		2	13	5	
4 administrators		2		1	1
6 experts	2	2		1	1
Rate	7%	17%	43%	27%	7%

Most of the managers said that they did not know whether emissions trading could help achieve carbon reduction in China. MA10 said that: 'I do not know much about emissions trading while carbon problem is a hot topic right now, so I cannot judge this question carelessly'. MA16 also argued that whether emissions trading could be successful in reducing carbon emissions was uncertain because the experiences of the Taiyuan SO_2 emissions trading program were still too limited. Five managers thought it was possible for China to use carbon emissions trading. MA1 said that: 'there are no differences between CO_2 and SO_2 in nature. Referring that the SO_2 emissions trading has successfully controlled the SO_2 emissions in Taiyuan, it is also possible to reduce CO_2 emissions by carbon emissions trading'. However, MA2 and MA3 showed relatively negative views on using carbon emissions trading. They suggested that it would be quite difficult to implement carbon emissions trading in China. MA2 said that:

> the Taiyuan SO_2 emissions trading program still has many limitations and the overall situation of its practice is not very good. If based on the existing SO_2 emissions trading practice, implementing carbon emissions trading in China would be quite difficult.

Meanwhile, no manager strongly supported or strongly opposed using emissions trading to achieve carbon reductions in China.

Considering the difficulties that the existing Taiyuan SO_2 emissions trading practice faced, AD3 and AD4 were pessimistic about a future carbon emissions trading program. AD3 argued that some preconditions for carbon emissions trading, such as an advanced carbon emissions exchange, were not ready in China. AD4 said that:

> managing and monitoring carbon emissions is difficult as there are too many CO_2 emission sources and the pollutions are too distributed, which will bring more difficulties for carbon emissions trading than SO_2 emissions trading. Not to mention, even in current Taiyuan SO_2 emissions trading program, the continuous online monitoring equipment is very limited.

But AD2 suggested that carbon emissions trading might be a good idea in China even though its implementation would be difficult at this stage. He explained that:

> some of the limitations of Taiyuan SO_2 emissions trading program could be owing to the fact that the participants in the program are too limited. For a nationwide carbon emissions trading program, this dilemma can be solved as there are enough carbon emissions sources. So carbon emissions trading could be more successful than the existing Taiyuan SO_2 emissions trading practice. However, some problems with existing emissions trading cannot be improved in the short term, such as a lack of national law in terms of emissions trading, so the implementation of carbon emissions trading in China is still difficult under current situation.

AD1 strongly supported using emissions trading to achieve carbon reduction in China. AD1 argued that:

> it is no doubt that Taiyuan SO_2 emissions trading program has successfully reduced the SO_2 emissions in Taiyuan city, while for carbon emissions, achieving carbon reductions is the first task, so carbon emissions trading could be an effective instrument.

Two experts, EX2 and EX5, opposed carbon emissions trading in China. EX2 listed two reasons to support his argument. First, the accumulated carbon emissions in the atmosphere are mainly due to the industrialized countries in the process of industrialization, while per capita emissions in China is still relatively low. The UNFCCC states 'common but different responsibilities' instead of requiring China to commit to a carbon reduction target. Therefore, China does not need to make such a commitment to restrain itself. Second, China remains a developing country with achieving economic growth being the top task, while the CO_2 emissions caps would have a conflicting effect on the pace of development. He said that:

> it is still too early for China to commit itself to reduce carbon emissions, adopting either carbon tax or carbon emissions trading. The introduction of either instrument in the near future will largely and negatively affect the energy sectors as well as the whole economy. Then China will never have the chance to catch up with the developed economics.

Agreeing with EX2's two reasons, EX5 was also worried that the special national conditions of politics and the markets in China made emissions trading not suitable for reducing carbon emissions. For example, some of the infrastructure for the free market as well as for emissions trading are not adequate for supporting a large-scale carbon emissions trading scheme in China.

EX1 and EX4 thought that it was very difficult to employ carbon emissions trading in China. EX1 argued that many concerns needed to be addressed before a domestic carbon emissions trading scheme is introduced in China, including whether the carbon emissions trading scheme would weaken China's economic growth and competitive advantage, whether it could be accepted by the enterprises, and how the carbon trading policy could be compatible with current environmental policies. EX4 said that:

> even though the carbon emissions trading scheme is theoretically effective and efficient, it is not expected that China will adopt it to limit carbon emissions in the short term. This is because carbon emissions trading has only been implemented in a few developed countries with limited experience, and it requires a strict monitoring and stringent enforcement to ensure the compliance.

However, EX6 argued that emissions trading might be a good policy option for China to achieve carbon reduction. He said that:

> the increasing CO_2 emissions and current command-and-control carbon regulations in China put China under great pressure to take a market-based instrument to achieve carbon reductions at the least cost. As China has got some lessons from existing water

pollutants as well as SO_2 emissions trading practice and also could learn experience from other successful emissions trading practices in western countries, carrying out a carbon emissions trading scheme in China could be possible. Carbon emissions trading may be a good policy option for solving China's carbon problem.

Furthermore, EX3 strongly supported the use of carbon emissions trading in China. He insisted that carbon emissions trading was becoming a worldwide trend, and that China had no reason to be out of step. Otherwise, China would lose a great opportunity to cooperate with other countries in mitigating carbon emissions and addressing the climate change problem.

5.3.2 Necessary considerations for China for carbon emissions trading

What are the necessary considerations for employing an emissions trading policy to mitigate carbon emissions in China? Four experts who were pessimistic about carbon emissions trading in China expressed views on this question. They suggested that the economic development level and market conditions in China as well as the legal base, enforcement and public acceptability of emissions trading need to be carefully assessed and discussed when considering carbon emissions trading policy in China (Table 5.7).

Table 5.7 Necessary considerations for China when using carbon emissions trading

Interviewees	Necessary considerations for China when using carbon emissions trading
EX1, EX2, EX5	Economic development level
EX5	Market conditions
EX1	Legal basis of emissions trading
EX4	Enforcement of emissions trading
EX1	Public acceptability of emissions trading

EX2, EX5 and EX1 suggested that China's economic development was the first consideration before carbon emissions trading could be implemented. EX2 argued that a mandatory carbon reduction cap was unfair and unfeasible for the rapidly developing China. China's economy continues to grow at a high rate and the process of urbanization is accelerating, which essentially leads to increased CO_2 emissions through the high demand for energy. The developed countries have already gone through the industrialization stage, so it is unfair to set the same standard for a developing country like China. Setting a mandatory emissions reductions target before 2020 would be at the expense of China's economic growth and urbanization. Thus as a low-income country and a low per capita discharger of CO_2, China cannot reduce carbon emissions through restraining its economic development. EX5 said that:

> the climate change issue is different from the conventional air pollution problems in mitigation options and economics. For example, the technology for reducing SO_2 is quite mature, but there is still no effective technology in mitigating CO_2 emissions and the alternative options are every expensive. The mitigation of carbon emissions needs to be supported by a strong economic basis. But whether the economic basis in China is strong enough to support reducing carbon emissions by carbon emissions trading policy should be analysed in advance.

In addition, EX1 suggested that how much a carbon emissions trading scheme would affect China's economic growth and the enterprises' competiveness should be accurately simulated and understood before any scheme was implemented. Complementary measures or policies should be considered to alleviate the negative impact of the carbon emissions trading.

The market conditions in China was another factor suggested by EX5:

> all the emissions trading program must be based on the principle of the free market mechanism to ensure the possibility of trading between enterprises. Is the market free enough to implement carbon emissions trading in China? This question includes two meanings. First, whether or not the participants are private enterprises? Second, whether or not the emissions trading market is regulated by the administrative department? This is a very important consideration for China to carry out carbon emissions trading.

EX1 argued that:

> China has never been a mature law-based society, and the enforcement is always disappointing. There are only some local regulations for local emissions trading practice. No emissions trading law at the country level has been established so far. The latest feedback from the emissions trading practice shows that the enforcement of emissions trading program is not good. So when considering using emissions trading to achieve carbon reductions, this is a problem that needs to be carefully examined.

EX4 argued that the enforcement of the emissions trading program decided how far the emissions trading practice was from the original plan. Even a well-designed emissions trading program, if not effectively enforced, would be most likely to fail.

He was worried that 'as emissions trading is not as mandatory as a tax, and lacks successful precedent in China, the enforcement ability is poor and needs to be improved before a comprehensive carbon emissions trading program is introduced'.

In addition, EX1 suggested considering the public acceptability of carbon emissions trading in implementing this policy:

> though in the context of China, the enterprises get used to obey the orders from the government, but increasing the enterprises' acceptability of the carbon emissions trading program could help the enterprises get more actively involved in developing low-carbon or non-carbon technology and so on.

5.4 Discussion

5.4.1 Comparing the Taiyuan SO_2 emissions trading practice to the theoretical emissions trading response model

Emissions trading can achieve both environmental and economic goals at the same time (Ellerman 2005). Emissions reductions have been effectively achieved in the Taiyuan SO_2 emissions trading program while cost savings do not seem to have been realised, according to the respondents in the case study, as most of the savings are theoretically achieved by trading yet only a few trades happened. Thus the Taiyuan SO_2 emissions trading program succeeded in realizing its environmental goal but may have failed to achieve its economic goal.

Innovation or investment in clean technology has been promoted under the Taiyuan SO_2 emissions trading program. However, the motivation for innovating and investing in clean technology was found merely to comply with the caps instead of resorting to the least expensive emission reduction method. Furthermore, though little direct or indirect investment was relocated after the Taiyuan SO_2 emissions trading program was implemented, the lack of leakage was mainly due to other factors related to companies' structures and customer locations rather than the policy itself.

According to the Theoretical Emissions Trading Response Model proposed by the emissions trading theory in Chapter 2, a successful emissions trading program would simultaneously reduce emissions, save costs, promote innovation and investment in clean technology, and would not lead to any leakage. Overall, the Taiyuan SO_2 emissions trading program seems not to be functioning anything like an ideal emissions trading model. The practice of the Taiyuan SO_2 emissions trading in China is quite different from the ideal.

5.4.2 Comparing the Taiyuan SO_2 emissions trading practice to emissions trading practices in western countries

Though the allowances trading market evolved slowly at the early stage of the US Acid Rain Program, the total amount of private trades was about 880 000 allowances in 17 transactions between May 1992 and October 1993, representing about 3% of all phase I (January 1995–December 1999) allowances (Rico 1995; Rose et al. 1993). Moreover, in 1993 the EPA offered 50 000 year 1995 ‘spot auction’ allowances and 100 000 year 2000 ‘advance auction’ allowances (EPA 1993). In comparison, the performance of the early stage of the Taiyuan SO_2 emissions trading market is poor. The major reasons for this can be first attributed to the flawed design and weak implementation of the program. Second, the participating enterprises’ managers and administrators do not fully understand emissions trading. Third, support measures for the trading market, such as emissions exchanges, were not established promptly. All these factors make the participants hesitant to engage in the trading, which results in an inactive emissions trading market.

Taking the linkage policy as an example, the enterprises in the US Acid Rain Program also must acquire permits to enter the market, but they could buy the permits from either existing enterprises or the EPA, as a small number of additional permits are auctioned by the EPA annually (Schmalensee et al. 1998). Evidence from the US Acid Rain Program suggests that the early allowance auctions can be a market starter, helping to provide a price signal to the nascent market (Rico 1995). By evaluating the SO_2 emissions trading in the US in 1998, Schmalensee et al. (1998) also argue that permit auctions in the US SO_2 emissions trading program may have facilitated both the price discovery process and the development of the permit trading market. However, the design of the Taiyuan SO_2 emissions trading program did not make good use of auctioning to activate the emissions trading market.

Just as the workers in the enterprises covered by the Taiyuan SO_2 emissions trading program did not really understand emissions trading, the same problem appeared in the US Acid Rain Program. Before the US Acid Rain Program, most of the affected units expressed clearly that they did not understand the market and would not trade allowances with other companies (Rico 1995). But with the meetings and workshops offered by the EPA, a total of 613 transactions were made in the first year (1995) and this number increased to 4198 in 2003, indicating that more participants understand the emissions trading market and choose allowances trading as the compliance strategy (EPA 2003b). However, seven years after the introduction of the Taiyuan SO_2 emissions trading program in 2003 the participating enterprises were still not knowledgeable enough about emissions trading. They still could not make the decisions necessary to fully utilise emissions trading and achieve the cost savings that this economic instrument could offer.

No literature has been found that discusses the importance of an emissions exchange in emissions trading programs like the US Acid Rain Program or the EU ETS. One explanation is that the markets in the US and the EU are free and mature enough for implementing the economic-based instrument of emissions trading and this is taken for granted. The market information is more symmetrical so that the affected enterprises can agree on the transactions independently. Another possible reason is that the Chicago Emissions Exchange in the US and the European Climate Exchange in the EU have developed very quickly since their establishment in 2003 and 2004 respectively, which promoted the development of the emissions trading markets. It has been confirmed by Mackenzie (2007) that allowances trading in the EU ETS can take place via brokers and on several organised exchanges, even in the form of carbon futures, by using the electronic trading platform, so a physical emissions exchange is comparatively not so important. However, China’s semi-free market situation makes an emissions exchange very significant to the Chinese emissions trading market. This may be the major reason for some interviewees proposing an emissions exchange for activating the emissions trading market.

5.4.3 Experience from the Taiyuan SO_2 emissions trading program

Even though the performance of the Taiyuan SO_2 emissions trading program is disappointing, some lessons can be learned from it for other emissions trading programs (and even for future carbon trading) in China. Economic instruments do not achieve least cost automatically and a poorly designed economic instrument may cost as much as command-and-control (Hufschmidt et al. 1983). The Taiyuan SO_2 emissions trading practice shows that the design of an emissions trading program is the first step and special attention needs to be paid to the key elements of the program, including allowances allocation method, allocation policy, linkage policy and so on. The EU ETS experienced extreme price fluctuations from 2005 to 2007 due to the politics of allocations, peaking at €31/t and sinking almost to zero, which is a carbon market failure (MacKenzie 2007).

Furthermore, even a well-designed ETS may not guarantee success without powerful enforcement. Experience from the Taiyuan SO_2 emissions trading practice suggests that the enforcement of an emissions trading program determines the performance of the program, so the enforcement should be swift, strict and strong. Because the institutional capacity of supervising is limited, the implementation of emissions trading may also have limitations. Experience in many countries has shown that local authorities and strong institutional support play important roles in the success of economic instruments (Huber et al. 1998). This is especially true for China as a developing country with a transitional economy which may adopt emissions trading with different institutional arrangements.

In addition, when using emissions trading in China, an active emissions trading market is of great importance in achieving cost savings. The interviews suggest that an emissions exchange would be a good organization for promoting and assisting trading, and so an exchange should be established before an ETS is implemented. Seminars and training on emissions trading should be provided for the participants to make sure that they know how to make the abatement decisions on emissions reductions.

5.4.4 Key challenges for implementing carbon emissions trading in China

In terms of the key challenges for implementing carbon emissions trading in China, the experts interviewed showed similar concerns about market conditions and legal authority as suggested in the literature. They questioned whether the Chinese market is free enough to carry out carbon emissions trading, and whether the legal authority is adequate enough to ensure the implementation of carbon emissions trading in China. Enforcement ability is another necessary consideration proposed by the experts for carbon emissions trading in China, which includes the emissions measurement mentioned by Zhang (2004) and Wang et al. (2002). In addition, the experts worried about whether the economic development level in China is strong enough to support a carbon emissions trading program. They also suggested that public acceptance of a carbon emissions trading program should be considered.

Zhang (2004) considered that emissions trading system was feasible for addressing the Chinese SO_2 pollution problem in spite of the fact that the Chinese market was not totally free and that Chinese society still lacked legal regulation. He believed that the market would be freer gradually and emissions trading practice would be guaranteed by the law in the near future. After several years' practice of SO_2 emissions trading in China, however, the performance of the Taiyuan SO_2 emissions trading program in this research shows that emissions trading still has a long way to go because the market is still not free enough to achieve trading and the legal authority is also not sufficient enough to ensure the smooth implementation of a emissions trading program in China.

5.4.5 The feasibility of using emissions trading to achieve carbon reductions in China

The difficulties of using carbon emissions trading in China identified by the interviewees have been discussed by other experts or researchers publicly. Jiang Kejun, a researcher from the Energy Research Institute of NDRC, argues that certain prerequisites of implementing carbon trading are not ready in China:, these include an effective management system, a mature legal system, a reliable information disclosure system, and scientific measurement and monitoring (Wang & Jiao 2011). All of these conditions could not be built up quickly, so a carbon tax is easier to use currently. Xiong Yan, chairman of the Beijing Environment Exchange, points out that issues such as an ambiguous policy planning and a weak legal basis exist in China in terms of a carbon emissions trading system (Bo 2010). Though some carbon trades have taken place in China, they were sporadic and truly market-oriented carbon trading has not happened. While carbon trading is mainly through the EU ETS, the US Chicago Climate Exchange, the Canada Montreal Climate Exchange and climate exchanges in Australia, the carbon trading market in developing countries is still in the preparatory stage (Xu 2011). It is projected that the carbon trading market in China would be very difficult to be as mature as that in western countries before 2030 when China reaches the peak of carbon emissions (Bo 2010). So, the improvement of the carbon trading market in China still has a long way to go. Cao Jing, an assistant professor from Tsinghua University, also suggests that a market mechanism and related legal basis still need to be developed in China (Cai 2011). As China has no experience in setting up an effective carbon trading market, the learning and adaption process needs a considerably long time, thus it is more appropriate to design and implement a carbon tax in China.

Though it is argued that CO_2 is a global problem, and therefore will have more market participants, the abatement cost of CO_2 is much more varied than that of SO_2 and, unlike the mature desulphurization technology, there has been no effective decarbonisation technology so far. Cost savings are more likely to be achieved in a carbon trading market and the affected enterprises would probably be more likely to choose carbon trading as the compliance strategy. Furthermore, the design of a carbon trading program could be initially ensured and the administrative implementation could be improved if done step by step. Considering that an emissions trading market is the most meaningful part of an emissions trading program, however, while the market situation in China is not free enough and the development of market liberalization is a long process, emissions trading may not be suitable for achieving carbon reduction targets in China in the short run. Therefore, a carbon tax might be a suitable alternative choice initially.

5.4.6 Comparing emissions trading and a carbon tax in the short term

The previous discussion concludes that carbon emissions trading may not be suitable for China to achieve carbon reductions target in the short run. Instead, a carbon tax is suggested as a more suitable option. Many experts have publicly expressed their views on using carbon tax policy (Cui 2009). Wang Dehua, an assistant researcher in the Finance and Taxation Research Office of the Chinese Academic of Social Science, advises that the carbon tax is necessary in China as it can increase the fiscal revenue as well as correcting the behaviours of enterprises and residents in using resources. Liu Dexun, the deputy director of the Global Climate Change Institute at Tsinghua University, argues that a carbon tax could vigorously promote the development of renewable energy sources and nuclear energy. Liu Huan, the vice president of the Faculty of Taxation at the Central University of Finance and Economics, suggests that a carbon tax could optimize the energy structure and enhance people's energy-saving awareness by raising the price of basic energy. The Research Institute for Fiscal Science of the Ministry of Finance in China suggests that a carbon tax is necessary for China to improve its environmental tax system (Research Institute for Fiscal Science 2009).

Yu Jie, the director of a China policy and research project, Climate Group, suggests that a carbon tax is more suitable for the Chinese context until enterprises' emission data could be monitored accurately (Bo 2010). Carbon trading has a higher requirement of the carbon emission data because enterprises have to know their historical as well as their future emissions. Furthermore, carbon emission permits are intangible goods. So the establishment of a perfect carbon trading market needs the market to be transparent and fair, and requires the support of a strong social credit system, which are all unachievable in the foreseeable future. In addition, enterprises affected by rising costs directly after a carbon tax is imposed would be simulated to apply energy-saving technologies and improve their industry.

However, some experts argue that a carbon tax is not the optimal option for China. Huang Jiefu (2010), a professor from Beijing Normal University, argues that most regions or countries such as the US, Japan, Korea and Taiwan plan to introduce carbon emissions trading rather than a carbon tax. Although Australia intended to introduce a carbon emission trading scheme, it adopted a carbon tax. Except for the small European countries of Denmark and Finland, a carbon tax has not been applied on a large scale. Furthermore, how to decide the carbon tax rate is another difficulty because the development of regions and the quality of enterprises are seriously uneven in China. Compared with the price signal created by trading, the carbon tax rate lacks flexibility and could not be adjusted at any time. While ChangCe Thinktank (2010) argues that a carbon tax could alleviate some of the international pressure on China, it cannot get clear benefits from the international world as the developed countries may still criticize China and impose trade sanctions if the carbon tax rate is too low. As well, a carbon tax may impact negatively on income distribution in China because the proportion of energy expenditure in the low-income population is greater than for the high-income population (ChangCe Thinktank 2010; Liang & Wei 2012).

By comparing a carbon tax and a carbon emissions trading scheme from three aspects – theory basis, abatement costs and effects on emission reductions – Zeng (2009) concludes that the implementation cost of a carbon tax is relatively low, which makes it more likely to be adopted by the government at the initial stage of an emission reductions policy. Carbon trading's advantageous effects on emission reductions and information cost, and its considerable potential on cross-border reductions (cooperation between developed and developing countries), means it is becoming the most important carbon reduction mechanism. Specific to China in the short term, Zeng (2009) proposes that China consider levying a carbon tax on some emission-extensive industries to promote technology transfer and structure adjustment while participating actively in the existing international carbon trading, and utilizing foreign funds and technologies to lower the carbon intensity in China. But in the long term China should strengthen the R&D of its carbon trading market as early as possible and launch pilots of permit trading at the appropriate time to promote the development of a domestic carbon trading market. Mei Dewen, general manager of the Beijing Environment Exchange, also thinks that China should first implement a carbon tax and then have both a carbon tax and carbon emissions trading schemes when the necessary conditions have been satisfied (Yan 2010).

Whether a carbon tax is a suitable policy for reducing carbon emissions in China is still a heated debate. Each side has their own sufficient and convincing reasons. Nevertheless, it could be noticed that most of the experts agree that a carbon tax is more suitable for the Chinese context at this stage while carbon trading is a future development. The findings from the case study of the Taiyuan SO_2 emissions trading program and the expert interviews in this research also suggest that an ETS may not be appropriate for reducing carbon emissions in China yet. However, the feasibility of adopting a carbon tax policy in China needs to be further assessed. Thus the research Q3 is proposed:

Is carbon tax a suitable policy for achieving carbon reductions in China?.

5.5 Conclusion

In summary, the introduction of the SO_2 emissions trading program in Taiyuan city has effectively reduced the SO_2 emissions, promoted innovation and investment in clean technology, and has not necessarily led to investment leakage. But the motivation of innovating and investing in clean technology is to comply with the caps and the absence of leakage is mainly due to factors important to the companies rather than to the policy itself. The interviews do not suggest any evidence that cost savings have been realized. Furthermore, it is argued that the Taiyuan SO_2 emissions trading program is better than previous command-and-control regulations, even though it has many problems such as a true SO_2 emissions trading market not being formed yet. Overall, it seems that the Taiyuan SO_2 emissions trading program is not functioning like the Theoretical Emissions Trading Response Model proposed by the emissions trading theory. It cannot be judged as a successful scheme in terms of the four key criteria.

Based on the findings from the Taiyuan SO_2 emissions trading program, it appears that emissions trading may not be suitable for China to achieve ambitious carbon reduction targets at this stage. The interview information about using emissions trading to achieve carbon reduction in China supports this conclusion. This is because the prerequisites of emissions trading in China – market condition, legal authority, economic development level and so on – are not sufficient. Thus, some researchers have suggested that a carbon tax might be more appropriate at this stage, with a carbon emission trading scheme in the longer term. However, whether a carbon tax will be effective for China needs to be further evaluated by an appropriate method.

Even though the performance of the Taiyuan SO_2 emissions trading program is disappointing, lessons on the design and the implementation of the program, and the operation of the emissions trading market can still be drawn from it. These have significant implications for other emissions trading programs, including a future carbon trading program in China. It is suggested that a workable emissions trading program should be well designed, effectively enforced and supported by relevant measures such as emissions exchanges.

Chapter 6 A carbon tax CGE model for China

6.1 Introduction

The findings from the case study and the interviews reported in Chapter 5 show that a carbon emissions trading scheme might not be suitable for China in the short term and that a carbon tax is probably more suitable for achieving any reduction target at this stage. According to the overall research design (Chapter 2, section 2.4), our research attention will therefore shift to the alternative economic instrument for emissions trading, which is the carbon tax. It has been argued by some researchers and shown by some practices that a carbon tax could be effective in reducing carbon emissions (Chapter 2, section 2.3). However, the environmental effectiveness of a carbon tax in China remains unknown due to a lack of knowledge and practice. Furthermore, debates on environmental policy often come to the issue as to whether or not the proposed policy will harm economic growth, and by how much (Wajsman 1995). This is particularly important for China as a developing country which has economic growth as its top priority. Therefore, whether a carbon tax is a suitable policy for reducing carbon emissions in China (research Q3) needs to be assessed by evaluating its effectiveness in reducing carbon emissions and its subsequent impact on the economy.

Computable General Equilibrium (CGE) models are argued to be the most appropriate approach for environmental policy analysis (Xie 1995; Zhang & Folmer 1998). They have also been applied to simulate the impacts of a carbon tax in many countries (see section 6.2.3). In order to explore the suitability of introducing a carbon tax in China, this research will also use a CGE model to simulate the effectiveness of a carbon tax in reducing carbon emissions as well as subsequent impacts on China's economy and energy structure. The 'Chinese carbon tax CGE model' can describe the new economy equilibrium of China after a carbon tax is imposed on the economic system. The modelling of CGE is crucial to the research purpose, but the construction of the database for the CGE model requires great effort because CGE models are always data hungry. In this chapter, a Chinese carbon tax

CGE model will be constructed and the data and solution for this model will be discussed.

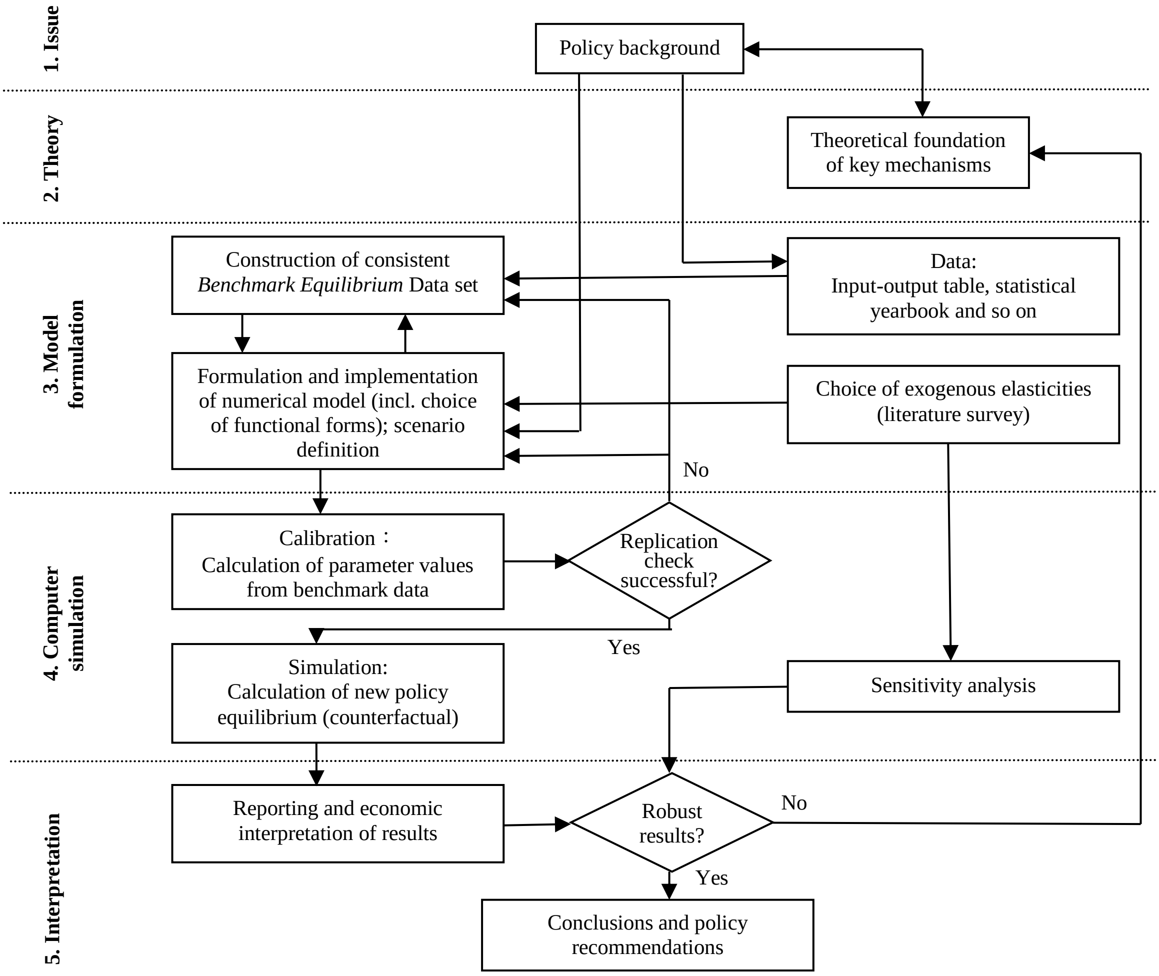
The rest of this chapter is structured as follows. Section 6.2 will briefly review the CGE modelling and present the reasons of employing a CGE model for evaluating the impacts of a carbon tax in China. In section 6.3 the Chinese carbon tax CGE model in this research will be described. The data for the CGE model will be given in section 6.4. Section 6.5 will discuss the software solutions for the CGE model.

6.2 CGE Modelling

6.2.1 Definition

The CGE modelling, also known as applied general equilibrium modelling, originated from the General Equilibrium Theory of Walras (Zhou & Wang 2002). It has a clear structure of the micro-economy and linkages between macro and micro-economic variables, thus it can describe the reactions among markets and simulate the direct or indirect impacts of a policy shock on the whole economy. The most common use of CGE models is to first calculate an initial equilibrium based on the benchmark data set (Wajsman 1995). Then, a new and 'counterfactual' equilibrium is calculated by changing some exogenous variables, usually a policy parameter such as a tax rate. So the impact of the policy change is revealed by a comparison of the two equilibria.

There is no precise definition of a CGE model. Condon et al. (1987) describe it as a model which numerically specifies an economy where supply and demand for goods and factors are made equal by adjusting the prices and quantities on the basis of Walrasian general equilibrium theory. Bergman (2005) considers it as a model that aims to quantify the impacts of a specific policy on the equilibrium allocation of resources and relative prices of goods and factors. Böhringer et al. (2003) point out that the essence of CGE economics is to derive policy insights by combining the general equilibrium theory with a consistent data set (most commonly from the National Accounts). In addition, Böhringer et al. (2003) summarize five main steps involved in conducting a CGE analysis (Figure 6.1). Particularly, this research will adopt these five main steps in constructing and using the Chinese carbon tax CGE model.



Source: Adapted from Böhringer et al. (2003, p. 3)

Figure 6.1 Steps in computable general equilibrium analysis

6.2.2 Why the CGE approach?

Apart from CGE models, other economic modelling approaches could also be applied in assessing the impacts of a carbon tax on carbon emissions reductions as well as the whole economy, such as the most well-known input-output and macroeconomic approaches. Several studies have discussed the relative strengths and weaknesses of different kinds of economic approaches and have shown the rationale for choosing the CGE approach for environmental policy analysis (Xie 1995; Zhang & Folmer 1998; Zhang & Nentjes 1998).

Zhang & Folmer (1998) assess six economic modelling approaches for estimating the cost of reducing carbon emissions (ad hoc, dynamic optimization, input-output, macroeconomic, CGE and hybrid), and highlight that CGE models are an appropriate tool for analyzing the economic effects of great changes in the demand and/or supply structure of an economy. Furthermore, Zhang and Nentjes (1998) argue that CGE models are preferred to input-output and macroeconomic models as they are based on solid microeconomic foundations while macroeconomic models pay more attention to time-series data. In addition, comparing to other modelling techniques, such as the input-output approach and linear programming, Xie (1995) summarizes four appealing features of the CGE approach for analyzing environmental policy: endogenous price and market determined features, supply and demand equated on Walrasian general equilibrium theory, supply and demand functions derived from the behavior of profit-maximizing producers and utility-maximizing consumers respectively, and non-linear technique and resources constraints.

Based on the preceding discussion, the CGE approach is best capable of simulating the results of a policy change or an external shock, which in our case is a carbon tax. This research aims to quantify the impact of a carbon tax in China, including the effects on emissions reductions, the macro-economy, sectoral production and competiveness, and energy consumption structures. Because the energy sectors are the main sources of CO_2 emissions, the model in this research emphasizes the energy sectors and their linkages to the rest of the economy. According to market theory, imposing a carbon tax on carbon energy will change the relative prices of goods. Carbon-free or low-carbon-containing goods and services become relatively cheaper than those of high carbon content. Such changes in the relative prices will lead to shifts away from high-carbon energy and carbon-intensive goods and services to low-carbon or carbon-free energy, goods and services. This will in turn have effects on the economic structure and on economic growth. Clearly, for analyzing such economy-wide effects, CGE models are most appropriate.

6.2.3 Carbon tax CGE model

The CGE model was pioneered by Johansen (1960) and Harberger (1962) and has been widely used in analyzing environmental policy since the beginning of the 1990s (Bergman 2005). It has been applied around the world in analysing the economic effects of limiting CO_2 emissions by means of a carbon tax . Examples are the works of Kemfert & Welsch (2000) for Germany, Wissema & Dellink (2007) for Ireland, Drouet et al. (2006) for Switzerland, Pempetzogloua & Karagiannib (2002) for Greece, Timilsina & Shrestha (2002) for Thailand, Al-Amin & Hamid (2009) for Malaysia, and Bruvoll & Larsen (2004) for Norway. Some researchers have also used a CGE model to simulate the impacts of a carbon tax in China (Garbaccio et al. 1999; Lu et al. 2010; The Chinese Study Group of Climate Change 2000; Wang et al. 2009b; Zheng & Fan 1999). Some selected literature on carbon tax CGE models is detailed in Table 6.1.

However, most of the carbon tax CGE research in China focuses on estimating the degree of CO_2 reductions, the impact on GDP or economic growth or the cushion effects of the complementary policies, and ignores the effects on energy structure. Zhang (1996) uses a time-recursive dynamic CGE model which emphasizes the relationships between economic activity, energy consumption and CO_2 emissions to analyze the Chinese economy-energy-environment system interactions simultaneously at both sectoral and macroeconomic levels. But he does not separate the energy sector into carbon and carbon-free sectors in his model and does not specifically examine the impact of a carbon tax on energy consumption patterns, such as switching from carbon-based energy to clean energy.

Compared with the existing carbon tax CGE models of the Chinese economy and environment, the Chinese carbon tax CGE model in this research provides three additional features. First, the electricity sector is divided into thermal power and clean energy according to the means of generating electricity, thereby attempting to simulate the impacts of a carbon tax on optimizing the energy structure more precisely. Second, the energy mix production function employs a constant elasticity of substitution (CES) function instead of the Cobb-Douglas function, which considers that the substitution elasticity between energy factors may not be equal to one. Third, the energy factors are nested one by one, which both overcomes the limitation that every two energy factors have the same substitution elasticity and facilitates an investigation of the changes of energy consumption structure.

Therefore, the CGE approach has been adopted in this research to meet the purpose of evaluating the impacts of a carbon tax in China, the results of which could answer research Q3 (*Is carbon tax a suitable policy for reducing carbon emissions in China?*). The impacts to be assessed not only include the effects on the CO_2 reductions, the economic growth and the sectoral production and competiveness as other works have done, but also will incorporate the effects on the energy consumption structure to fill the research gap in China. The next section will describe and explain the construction of the Chinese carbon tax CGE model.

Table 6.1 Some selected literature on the carbon tax CGE model.

Literature	Research region	Research purpose	Model type	Main findings
Kemfert & Welsch (2000)	Germany	Assess the economic effects of CO_2 emission limits for Germany by using econometrically estimated substitution elasticities between energy, capital and labour	Dynamic multi-sector CGE model	Compared with ‘standard’ substitution elasticities from the literature, it finds lower tax rates and tax revenues, and a more stable revenue/GDP ratio.
Wissema & Dellink (2007)	Ireland	Quantify the impact of the implementation of carbon taxation to reduce CO_2 in Ireland	Energy-environment-AGE model	A carbon tax of €10-15/ton of CO_2 could reduce CO_2 emissions in Ireland by 25.8% compared to 1998 levels. Welfare would fall a bit while production and consumption patterns would change more significantly. The carbon tax greatly simulates the use of renewable energy and reduces the use of peat and coal.
Drouet et al. (2006)	Switzerlan d	Evaluate the impacts of CO_2 constraints on the Swiss economy through a carbon tax	Multi-sectoral, multi-regional, dynamic-recursive GEMINI-E3 model	A CO_2 abatement of 20% by 2020 and 50% by 2050 compared to 1990 levels could be achieved by US$468 and US$1440 respectively. The marginal abatement costs of CO_2 emissions are relatively higher in Switzerland than in other developed countries.
Pempetzogloua & Karagiannib (2002)	Greece	Investigate the potential effects of a carbon tax on the Greek economy	Dynamic CGE model	A carbon tax would decrease energy products demand and the total production of Greece, and it would affect competitiveness negatively. Energy intensive industries will probably be the most heavily and negatively affected industries.
Timilsina & Shrestha (2002)	Thailand	Examine the economic and environmental impacts of a carbon tax in Thailand	Static CGE model	If total government revenue is kept neutral, a carbon tax with revenue redistributed to households through a lump-sum transfer would cause a larger welfare loss than when revenue is used to finance the cuts in pre-existing distortionary factor tax rates.
Al-Amin & Hamid (2009)	Malaysia	Simulate the economic impacts of a carbon tax policy in Malaysia	Static CGE model	The carbon tax policy could achieve reasonable environment targets without losing the investment and government revenue.

Literature	Research region	Research purpose	Model type	Main findings
Bruvoll & Larsen (2004)	Norway	Evaluate the specific effect of carbon tax in Norway	Static AGE model	The carbon tax effect has been modest despite considerable taxes and price increases for some fuel-types. Due to extensive tax exemptions and relatively inelastic demand in the carbon taxation sectors, the carbon tax contributed to only 2% reductions in emissions.
Zhang (1996)	China	Estimate the economic implications of carbon abatement for the Chinese economy	Time-recursive dynamic CGE model	Large carbon reductions can only be achieved by ever-larger carbon tax. If the carbon tax revenues were used to offset the indirect taxes, the negative impacts of carbon tax on GNP and welfare would be reduced.
Garbaccio et al. (1999)	China	Examine the use of carbon taxes to reduce CO_2 emissions in China	Dynamic CGE model	There is a potential of 'double dividend', a decrease in CO_2 and a long run increase in GDP and consumption.
Lu et al. (2010)	China	Explore the impact of carbon tax on Chinese economy and the cushion effects of the complementary policies	Dynamic recursive CGE model	The carbon tax policy can largely reduce the carbon emissions with a relatively small impact on the GDP. And the complementary policies used together with carbon tax will help to reduce the negative impacts of a carbon tax on economy.
Wang et al. (2009b)	China	Simulate the impacts of carbon tax on Chinese economy, especially on energy saving and carbon reductions	IPAC-SGM CGE model (Integrated policy analysis model for China-second generation model)	A low-rate carbon tax will significantly reduce carbon emissions while having little impact on Chinse economy.
Liang (2007)	China	Simulate the impacts of a carbon tax policy in China	Recursive dynamic CGE model	By relieving or subsidizing production sectors, the negative impact of carbon tax on the economy and on the energy- and trade-intensive sectors could be alleviated.
The Chinese Study Group of Climate Change (2000)	China	Compute the impacts of carbon tax on the economy	CGE model	Low-intensity carbon tax policy will not significantly slow down economic growth. But it can effectively reduce the carbon emissions and the growth of energy consumption, and improve the energy consumption structure.
Zheng & Fan (1999)	China	Assess the impacts of limiting CO_2 emissions on Chinese economy by a means of carbon tax	A static CGE model	The cost of mitigating CO_2 emissions by carbon tax depends on the emissions reduction target, the reaction time of carbon tax and other complementary policies, such as whether other taxes are reduced.

6.3 Chinese carbon tax CGE model

On the basis of the research purpose, a static, multi-sectoral, open economy carbon tax CGE model of the Chinese economy has been developed. It uses data from 2007 and covers eleven economic sectors. Dynamic CGE models are argued to have more advantages than general static CGE models: they not only tell the researcher what the new long-run equilibrium is and what the impact of the policy changes is (as static CGE models do), but they also indicate how long the economy will take to get the new equilibrium (Wajsman 1995). But a static CGE model is believed to be enough for analysing the shock of a carbon tax on an economy in this research. This research focuses on the impact of levying a carbon tax rather than how it is achieved. In other words, this research does not care about the transit from one equilibrium to another, so there is not much difference between dynamic and static CGE models. Moreover, a dynamic CGE model needs much more data to support it, which may use more estimated data when resolving the model and in turn reduces the reliability of the model results. In addition, the researcher has limited time and resources.

The carbon tax CGE model in this research considers four agents: households, enterprises, government and foreign countries. The three basic types of production factors involved are labour, capital and energy, while energy is further divided into coal, oil, natural gas, thermal power and clean energy. The first four kinds of energy are considered as carbon energy and clean energy is the carbon-free energy. The economic system is grouped into eleven sectors on the basis of the standard 42 sectors used in China's 2007 Input-output (I/O) table (see Table 6.2 for the sector classification). Sectors 1–6 are associated with the production of goods and services, while Sectors 7–11 relate to the supply and distribution of energy. The model is made up of eight modules: production, price, income, expenditure, saving and investment, trade, environment and market equilibrium.

Table 6.2 Classification of producing sectors in the CGE model based on the 2007 input-output table

Sectors in Chinese carbon tax CGE model	42-Sector in I/O table
1. Agriculture	01
2. Heavy industry	04, 05, 12–22
3. Light industry	06-10
4. Transport and communications	27, 28
5. Construction	26
6. Services	24, 25, 29–42
7. Coal	02
8. Oil	03[a], 11
9. Natural gas	03[b]
10. Thermal power	23[c]
11. Clean energy (hydropower, nuclear power, wind power)	23[d]

a & b: The natural gas sector is part of the oil sector. It is separated from the oil sector using the *China Statistical Yearbook 2008*.

c & d: The clean energy sector is part of the electricity sector. It is separated from the electricity sector using the Electricity Balance Table in the *China Statistical Yearbook 2008*. According to the way of generating electricity, the electricity sector could be divided into thermal power, hydropower, nuclear power and wind power. The last three kinds of electricity are classified in the clean energy sector in this research.

It is assumed that the market is made up of numerous producers with the same pursuance and the goal for each producer is profit maximization in production. All households are consumers and are maximizing their consumption utility. The market is perfectly competitive and both producers and consumers are price takers. The capital stock in each sector can flow among sectors in every single year. The labour force is fully employed and is capable of floating freely from one sector to another. As a ‘small country’[21], China is assumed to take international prices.

The set of all the activity sectors is I, and the set of all the commodity sectors is J. Each activity sector is assumed to produce one commodity. In describing the equations, the endogenous variables are written in upper-case Latin letters without a bar, whereas the exogenous variables are denoted by upper-case Latin letters with a bar and the parameters are indicated by lower-case Latin letters or lower-case Greek letters. The meaning of a symbol is explained on the first use. Table 6.3 gives a

[21] ‘Small country’ assumption: for a modelled country or region, there are imports from outside of the economic system. For all its imports, the assumed share of the modelled economy in the world trade is so small that it faces an infinitely elastic supply curve at the prevailing world price (Lu et al. 2009). Though China may have influence on the price of some products, this assumption is necessary as it makes the modelling job easier.

summary of all the equations of this Chinese carbon tax CGE model. Moreover, Table 6.4 lists all the variables and parameters involved in this model.

6.3.1 Production

All sectors are assumed to operate at constant returns to scale. In each sector the gross output is produced using capital, labour, five energy inputs and intermediate inputs, with the substitution taking place across energy inputs, capital and labour. But there is no substitution between intermediate inputs and other inputs (e.g., labour, capital and energy) and among intermediate inputs. The production functions in the model take the CES functional form, except the composition function of non-energy intermediate inputs that takes the Leontief functional form.

The nesting hierarchy of the CGE model is depicted in Figure 6.2. Starting from the bottom, the production function is characterized by CES aggregations of oil, natural gas, coal, thermal power and clean energy one-by-one to form an energy mix. Capital and energy are combined to form a capital-energy mix. Then, the capital-energy mix and labour are combined to form a labour-capital-energy mix. Finally, all the non-energy intermediate inputs along with labour-capital-energy mix generate the total outputs. These nested production functions and their corresponding input ratio functions can be expressed as follows:

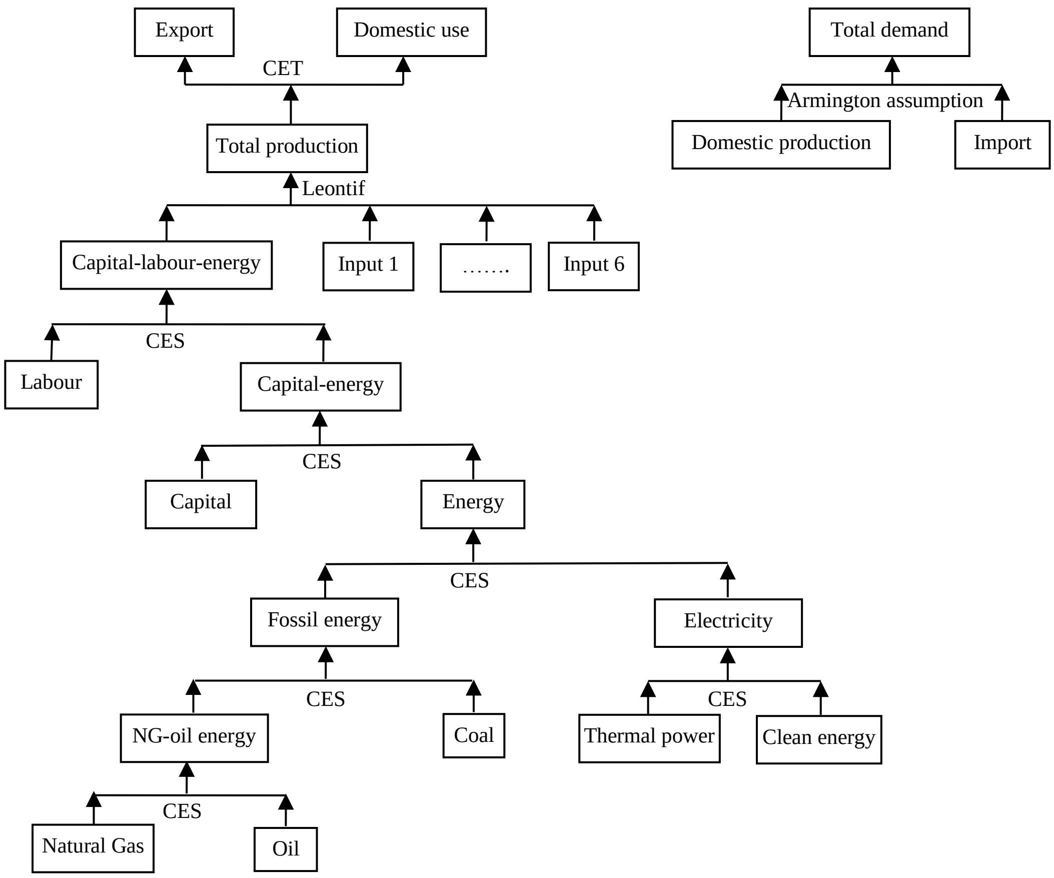


Figure 6.2 Nesting structure of production in the CGE model

$$\mathrm{QNGO_i} = \alpha_i^c[\delta_i^c\,\mathrm{QNG_i}^{\rho_i^c} + (1-\delta_i^c)\mathrm{QO_i}^{\rho_i^c}]^{\frac{1}{\rho_i^c}}, \qquad i \in I$$

where

$\mathrm{QNGO_i}$ - Input of NG-oil mix in sector i

$\mathrm{QNG_i}$ - Input of natural gas in sector i

$\mathrm{QO_i}$ - Input of oil in sector i

α_i^c - Transforming coefficient in the NG-oil mix function of sector i

δ_i^c - Share of natural gas in the NG-oil mix function of sector i

ρ_i^c - Substitution parameter between natural gas and oil in sector i. In addition, $\rho_i^c = (\sigma_i^c - 1)/\,\sigma_i^c$, σ_i^c denotes the substitution elasticity between natural gas and oil in sector i.

$$\frac{\mathrm{QNG_i}}{\mathrm{QO_i}} = [\frac{\delta_i^c}{1-\delta_i^c}\cdot\frac{\mathrm{PF_8}}{\mathrm{PF_9}}]^{\frac{1}{1-\rho_i^c}}, \qquad i \in I$$

where

PF_j - Price of energy type j, j equals to 7,8,9,10,11. So PF_8 indicates the price of oil and PF_9 denotes the price of natural gas

$$QFE_i = \alpha_i^f [\delta_i^f QNGO_i^{\rho_i^f} + (1 - \delta_i^f) QC_i^{\rho_i^f}]^{\frac{1}{\rho_i^f}}, \qquad i \in I$$

where

QFE_i - Input of fossil energy mix in sector i

QC_i - Input of coal in sector i

α_i^f - Transforming coefficient in the fossil energy mix function of sector i

δ_i^f - Share of NG-oil mix in the fossil energy mix function of sector i

ρ_i^f - Substitution parameter between NG-oil mix and coal in sector i

$$\frac{QNGO_i}{QC_i} = [\frac{\delta_i^f}{1 - \delta_i^f} \cdot \frac{PF_7}{PNGO_i}]^{\frac{1}{1-\rho_i^f}}, \qquad i \in I$$

where

$PNGO_i$ - Price of NG-oil mix in sector i

PF_7 - Price of coal

$$QEL_i = \alpha_i^s [\delta_i^s QTP_i^{\rho_i^s} + (1 - \delta_i^s) QCE_i^{\rho_i^s}]^{\frac{1}{\rho_i^s}}, \qquad i \in I$$

where

QEL_i - Input of electricity mix in sector i

QTP_i - Input of thermal power in sector i

QCE_i - Input of clean energy in sector i

α_i^s - Transforming coefficient in the electricity function of sector i

δ_i^s - Share of thermal power in the electricity function of sector i

ρ_i^s - Substitution parameter between thermal power and clean energy in sector i

$$\frac{QTP_i}{QCE_i} = [\frac{\delta_i^s}{1 - \delta_i^s} \cdot \frac{PF_{11}}{PF_{10}}]^{\frac{1}{1-\rho_i^s}}, \qquad i \in I$$

where

PF_{10} - Price of thermal power

PF_{11} - Price of clean energy

$$QED_i = \alpha_i^e [\delta_i^e QFE_i^{\rho_i^e} + (1 - \delta_i^e) QEL_i^{\rho_i^e}]^{\frac{1}{\rho_i^e}}, \qquad i \in I$$

where

QED_i - Input of energy mix in sector i

α_i^e - Transforming coefficient in the energy mix function of sector i

δ_i^e - Share of fossil energy in the energy mix function of sector i

ρ_i^e- Substitution parameter between fossil energy and electricity in sector i

$$\frac{QFE_i}{QEL_i} = [\frac{\delta_i^e}{1-\delta_i^e} \cdot \frac{PEL_i}{PFE_i}]^{\frac{1}{1-\rho_i^e}}, \qquad i \in I$$

where

PEL_i - Price of electricity mix in sector i

PFE_i - Price of fossil energy mix in sector i

$$QKED_i = \alpha_i^n[\delta_i^n \, QKD_i^{\rho_i^n} + (1-\delta_i^n)QED_i^{\rho_i^n}]^{\frac{1}{\rho_i^n}}, \qquad i \in I$$

where

$QKED_i$ - Input of capital-energy mix in sector i

QKD_i - Input of capital in sector i

α_i^n - Transforming coefficient in the capital-energy mix function of sector i

δ_i^n - Share of capital in the capital-energy mix function of sector i

ρ_i^n - Substitution parameter between capital and energy in sector i

$$\frac{QKD_i}{QED_i} = [\frac{\delta_i^n}{1-\delta_i^n} \cdot \frac{PED_i}{(1+tk) \cdot WK}]^{\frac{1}{1-\rho_i^n}}, \qquad i \in I$$

where

PED_i - Price of energy mix in sector i

WK - Price of capital (the rental rate)

tk - Value-added tax rate for capital

$$QLKED_i = \alpha_i^m[\delta_i^m \, QLD_i^{\rho_i^m} + (1-\delta_i^m)QKED_i^{\rho_i^m}]^{\frac{1}{\rho_i^m}}, \qquad i \in I$$

where

$QLKED_i$ - Input of labour-capital-energy mix in sector i

QLD_i - Input of labour in sector i

α_i^m- Transforming coefficient in the labour-capital-energy mix function of sector i

δ_i^m - Share of labour in the labour-capital-energy mix function of sector i

ρ_i^m- Substitution parameter between labour and capital-energy mix in sector i

$$\frac{QLD_i}{QKED_i} = [\frac{\delta_i^m}{1-\delta_i^m} \cdot \frac{PKED_i}{(1+tl) \cdot WL}]^{\frac{1}{1-\rho_i^m}}, \qquad i \in I$$

where

WL - Price of labour (wage rate)

$\mathrm{PKED_i}$ - Price of capital-energy mix in sector i

tl - Value-added tax rate for labour

$$\mathrm{QA_i} = \sum_{j=1}^{6} \mathrm{QINT_{ji}} + \mathrm{QLKED_i}\,, \qquad \mathrm{i} \in \mathrm{I}$$

where

$\mathrm{QA_i}$ - Aggregate output in sector i

$\mathrm{QINT_{ji}}$ - Intermediate input of commodity j in sector i

$$\mathrm{QINT_{ji}} = \alpha_{ji} \cdot \mathrm{QA_i}\,, \qquad \mathrm{i} \in \mathrm{I}, \mathrm{j} \in \mathrm{I}$$

where

α_{ji} - The intermediate input of j for each unit of output in sector i

6.3.2 Price

The price module describes all the price functions in the model: the prices of energy types, NG-oil mix, fossil energy, electricity, energy mix, capital-energy mix and labor-capital-energy mix, the aggregate producer price, the imports and exports price, the composite price and sale price of commodity. The introduction of a carbon tax on energy would in turn increase the price of energy. Assume that the producers transfer all the carbon tax to the corresponding energy. So after levying a carbon tax, the new price of the energy includes the relative carbon tax. This process could be written as

$$\mathrm{PF_j} = \left(1 + \mathrm{tcva_j}\right) \cdot \mathrm{PQ_j}\,, \qquad \mathrm{j} = 7,8,9,10,11$$

where

$\mathrm{tcva_j}$ - ad valorem carbon tax rate of energy type j. It is converted from a given carbon tax rate. See the environment module for more details.

Price of NG-oil mix:

$$\mathrm{PNGO_i} \cdot \mathrm{QNGO_i} = \mathrm{PF_9} \cdot \mathrm{QNG_i} + \mathrm{PF_8} \cdot \mathrm{QO_i}\,, \qquad \mathrm{i} \in \mathrm{I}$$

Price of fossil energy:

$$\mathrm{PFE_i} \cdot \mathrm{QFE_i} = \mathrm{PNGO_i} \cdot \mathrm{QNGO_i} + \mathrm{PF_7} \cdot \mathrm{QC_i}\,, \qquad \mathrm{i} \in \mathrm{I}$$

Price of electricity:

$$\mathrm{PEL_i \cdot QEL_i = PF_{10} \cdot QTP_i + PF_{11} \cdot QCE_i}\,, \qquad i \in I$$

Price of energy mix:

$$\mathrm{PED_i \cdot QED_i = PFE_i \cdot QFE_i + PEL_i \cdot QEL_i}\,, \qquad i \in I$$

Price of capital-energy mix:

$$\mathrm{PKED_i \cdot QKED_i = (1 + tk) \cdot WK \cdot QKD_i + PED_i \cdot QED_i}\,, \qquad i \in I$$

Price of labor-capital-energy mix

$$\mathrm{PLKED_i \cdot QLKED_i = (1 + tl) \cdot WL \cdot QLD_i + PKED_i \cdot QKED_i}\,, \qquad i \in I$$

where

$PLKED_i$ - Price of labour-capital-energy mix in sector i

$$\mathrm{PA_i \cdot QA_i} = \sum_{j=1}^{6} \left(\alpha_{ji} \cdot \mathrm{PQ_j}\right) + \mathrm{PLKED_i \cdot QLKED_i}\,, \qquad i \in I$$

where

PA_i - Aggregate producer price in sector i

PQ_j - Sale price of commodity j in domestic market

According to the ‘small-country’ assumption, Chinese takes the world market prices of imports and exports (pwm_j and pwe_i). The world market prices are in US dollars, then the exchange rate represents the price of a dollar in terms of the Chinese currency (RMB¥).

$$\mathrm{PM_j = pwm_j \cdot \left(1 + tm_j\right) \cdot EXR}\,, \qquad j \in J$$

where

PM_j - Domestic price of imports of commodity j (in RMB¥)

EXR - Exchange rate between US$ and RMB¥

pwm_j - World price of imports of commodity j (in US$)

tm_j - Import tariff rate of commodity j

In order to encourage exports, the export tariff rates for commodities are normally zero. Thus the domestic prices of exports can be written as

$$\mathrm{PEX_i = pwe_i \cdot EXR}\,, \qquad i \in I$$

where

PEX_i - Domestic price of exports in sector i (in RMB¥))

pwe_i - World price of exports in sector i (in US$)

The producer price in sector i can be written as weighted average of

$$PA_i \cdot QA_i = PDA_i \cdot QDA_i + PEX_i \cdot QEX_i \ , \qquad i \in I$$

where

PDA_i - Domestic price for commodity produced in sector i

QDA_i - Total domestic demand for commodity produced in sector i

QEX_i - Exports in sector i

The sale price for commodity j in the domestic market, PQ_j, is the price paid by the domestic demanders. It is specified as

$$PQ_j \cdot QQ_j = PDC_j \cdot QDC_j + PM_j \cdot QM_j \ , \qquad j \in J$$

where

QQ_j - Total demand of commodity j in domestic market

PDC_j - Demand price for commodity j produced and sold domestically

QDC_j - Total domestic demand for domestic commodity j

QM_j - Imports of commodity j

As it is assumed that one activity sector only produces one commodity, the price and quantity of activity and commodity that is produced and sold domestically are the same. The relationship can be described as

$$QDC_j = \sum_i IDENT_{ij} \cdot QDA_i$$

$$PDC_j = \sum_i IDENT_{ij} \cdot PDA_i$$

where

$IDENT_{ij}$ - Elements of unit matrix

6.3.3 Incomes

The income module includes four parts: household, enterprise (pre-tax) and government incomes and gross domestic production (GDP). Total household income is generated from four sources: labor income; distributed capital income from enterprises; transfers from enterprises; and transfers from the government. In the context of carbon tax, a part of the carbon tax revenues may be redistributed to households for compensating the loss they suffered from the carbon tax. Thus the household income function can be written as

$$\mathrm{YH} = \mathrm{WL} \cdot \mathrm{QLS} + \mathrm{shif_{hk}} \cdot \mathrm{WK} \cdot \mathrm{QKS} + \mathrm{transfr_{hg}} + \mathrm{transfr_{he}} + \mathrm{shif_{hg}} \cdot \mathrm{CR}$$

where

YH - Household income

QLS - Labour supply

QKS - Capital supply

CR - Total carbon revenue

$\mathrm{shif_{hk}}$ - Share of total capital income for households

$\mathrm{transfr_{hg}}$ - Transfer payment from government to households

$\mathrm{shif_{hg}}$ - Ratio of the carbon tax revenue redistributed to households

The enterprise pre-tax income includes capital income distributed to enterprises and transfer payment from the government to the enterprises, and excludes transfer payment from the enterprises to the households.

$$\mathrm{YENT} = (1 - \mathrm{shif_{hk}}) \cdot \mathrm{WK} \cdot \mathrm{QKS} + \mathrm{transfr_{eg}} - \mathrm{transfr_{he}}$$

where

YENT - Enterprise pre-tax income

$\mathrm{transfr_{eg}}$ - Transfer payment from government to enterprises

$\mathrm{transfr_{he}}$ - Transfer payment from enterprises to households

The revenues collected by the government include value-added tax on labour and capital, individual income tax, enterprise income tax, tariffs, and net foreign borrowing. With a carbon tax, there would be additional government revenue. The government revenue can thus be expressed as

$$\mathrm{YG} = \sum_{i \in I} (\mathrm{tl} \cdot \mathrm{WL} \cdot \mathrm{QLD_i} + \mathrm{tk} \cdot \mathrm{WK} \cdot \mathrm{QKD_i}) + \mathrm{ti_h} \cdot \mathrm{YH} + \mathrm{ti_{ent}} \cdot \mathrm{YENT} + \sum_{j \in I} (\mathrm{tm_j} \cdot \mathrm{pwm_j} \cdot \mathrm{QM_j} \cdot \mathrm{EXR}) + (1 - \mathrm{shif_{hg}}) \cdot \mathrm{CR} + \mathrm{transfr_{gf}}$$

where

YG - Government income

ti_h - Individual income tax rate

ti_{ent} - Enterprise income tax rate

$transfr_{gf}$ - Net foreign borrowing

The total economic level in China is measured by real GDP, calculated in the expenditure method: GDP = household consumption + government purchase + investment + net exports (exports - imports). Thus the real GDP function can be written as

$$GDP = \sum_{j \in J} \left(QH_j + \overline{QG}_j + \overline{QINV}_j - QM_j \right) + \sum_{i \in I} QEX_i$$

where

GDP - Real gross domestic production of China

QH_j - Household consumption of commodity j (in quantity)

$\overline{QG}_j$ - Government purchase of commodity j (in quantity)

$\overline{QINV}_j$ - The quantity investment of commodity j

Nominal GDP can be expressed as

$$\overline{PGDP} \cdot GDP = \sum_{j \in J} PQ_j \cdot \left(QH_j + \overline{QINV}_j + QG_j \right) + \sum_{i \in I} PEX_i \cdot QEX_i - \sum_{j \in J} PM_j \cdot QM_j + \sum_{j \in J} tm_j \cdot pwm_j \cdot QM_j \cdot EXR$$

where

$\overline{PGDP}$ - Price index of GDP, it is chosen as the basic price in this model, so $\overline{PGDP}$ = 1.

6.3.4 Expenditure

The expenditure module determines the demands for goods and services by households and the government. Household disposable income is the household income minus individual income tax. Household expenditure is determined by the disposable income and marginal propensity to consume (MPC). The utility function for households employs the Cob-Douglas function, thus the households' expenditure for commodity j can be expressed as

$$PQ_j \cdot QH_j = shrh_j \cdot mpc \cdot (1 - ti_h) \cdot YH\,, \qquad j \in J$$

where

$shrh_j$ - Share parameter of household expenditure on commodity j

mpc - Marginal propensity to consume

Government expenditure consists of the purchase for commodities and government transfers to households and enterprises. The quantity of government purchase of each commodity is set exogenously. The government expenditure can be written as

$$EG = \sum_{j \in J} PQ_j \cdot \overline{QG}_j + transfr_{hg} + transfr_{eg}$$

where

EG - Government expenditure (in money)

6.3.5 Saving and investment

The saving functions describe the formation of household saving, enterprise saving and government saving. Household saving is a function of marginal propensity to save (MPS) and household disposable income.

$$HSAV = (1 - mpc) \cdot (1 - ti_h) \cdot YH$$

where

HSAV - Household saving

Enterprise saving equals the enterprise pre-tax income minus the enterprise income tax.

$$ENTSAV = (1 - ti_{ent}) \cdot YENT$$

where

ENTSAV - Enterprise saving

Government saving is a function of government income and government expenditure.

$$GSAV = YG - EG$$

where

GSAV - Government saving

The quantity of investment is determined outside the model (Chang 2010).

$$EINV = \sum_{j \in J} PQ_j \cdot \overline{QINV_j}$$

EINV - Total investment (in money)

6.3.6 Trade

Constant elasticity of transformation (CET) function is used to allocate domestic products between domestic consumption and exports (Chang 2010; Zhang 1996).

$$QA_i = \alpha_i^t [\delta_i^t QDA_i^{\rho_i^t} + (1 - \delta_i^t) QEX_i^{\rho_i^t}]^{\frac{1}{\rho_i^t}}, \qquad i \in I$$

where

α_i^t - Transforming coefficient in the CET function of sector i

δ_i^t - Share parameter in the CET function of sector i

ρ_i^t - Substitution parameter between domestic consumption and exports in sector i

$$\frac{QDA_i}{QEX_i} = \left(\frac{\delta_i^t}{1 - \delta_i^t} \cdot \frac{PEX_i}{PDA_i}\right)^{\frac{1}{1-\rho_i^t}}, \qquad i \in I$$

The relationship between imported products and domestic supply is described by the Armington assumption (1969), as they are not completely the same and are partly substitutable.

$$QQ_j = \alpha_j^q [\delta_j^q QDC_j^{\rho_j^q} + (1 - \delta_j^q) QM_j^{\rho_j^q}]^{\rho_j^q}, \qquad j \in J$$

where

α_j^q - Transforming coefficient in the Armington function of commodity j

δ_j^q - Share parameter in the Armington function of commodity j

ρ_j^q - Substitution parameter between domestic supply and imports of commodity j

$$\frac{QDC_j}{QM_j} = \left(\frac{\delta_j^q}{1 - \delta_j^q} \cdot \frac{PM_j}{PDC_j}\right)^{\frac{1}{1-\rho_j^q}}, \qquad j \in J$$

6.3.7 The environment

The carbon tax is an excise tax, which is expressed as a fixed amount of Chinese currency per tonne of carbon emissions. Therefore the fuel-specific tax rates differ considerably between different types of fossil energy due to different carbon contents. In this research, it is assumed that the carbon tax is applied to the production of three kinds of fossil energy[22] – coal, oil and natural gas. Moreover, the carbon tax is levied on domestically used fossil energy. Thus exported fossil energy is exempt from carbon tax while imported fossil energy is included in a carbon tax. The carbon emissions from each fossil energy sector are estimated by the intermediate consumption and final household consumption of this energy. The equations of carbon emissions from the coal, oil and natural gas sectors can be expressed respectively as follows [23] (Zheng & Fan 1999).

$$EM_7 = (\sum_{i \in I} QC_i + \overline{HE}_7) \cdot em_7 \cdot \mu_7$$

$$EM_8 = (\sum_{i \in I} QO_i + \overline{HE}_8) \cdot em_8 \cdot \mu_8$$

$$EM_9 = (\sum_{i \in I} QNG_i + \overline{HE}_9) \cdot em_9 \cdot \mu_9$$

where

EM_j - Carbon emissions of energy type j

$\overline{HE}_j$ - Household consumption of energy type j (in quantity)

em_j - Carbon emissions coefficient of energy type j, tC/t for coal and oil, and tC/m^3 for natural gas

μ_j - Conversion coefficient of energy type j (considering burning ratio and inefficient loss)

Revenue generated from the carbon tax for each fossil energy sector can be estimated as

$$CR_j = tc \cdot EM_j\,, \qquad j = 7,8,9,10,11$$

[22] There are two bases of levying a carbon tax: consumption and production. If the carbon tax was based on the consumption of energy, there would be a double taxation. For example, the transport sector emits CO_2 because of using petrol, and then a carbon tax could be imposed based on the carbon content of petrol. But if oil, the input for producing petrol, was taxed then double taxation occurs. Thus we should only tax direct burning fossil energy. However, this makes it difficult for carbon tax collection as we need to classify the fossil energy either as final goods or as intermediate inputs. The input-output table is not detailed enough for adopting this kind of carbon tax. Compared to a consumption-based carbon tax, the production-based carbon tax is much easier to handle. In this research, we tax all the carbon content of the fossil energy, but not all the carbon content will go into the air in the form of CO_2. For example, when oil is used to produce plastic, the carbon in the plastic does not form into CO_2. However, one point that should be noted is that if all the fossil energy is burnt, the final result of both tax approaches is the same (Zheng & Fan 1999).

[23] In order to keep the expression of the model consistent, the equations of carbon emissions from the thermal power and clean energy sectors should be given as well. However, as the carbon tax does not cover the carbon emissions from thermal power and clean energy, the emissions from these sectors are considered zero and the relative equations are omitted.

where

CR_j - Carbon revenue of energy type j

tc - Carbon tax rate, expressed as a fixed amount of Chinese currency per tonne of carbon

Carbon tax is exogenous to the model. Based on the given level of a carbon tax, an ad valorem carbon tax rate of each energy type is calculated as follows:

$$tcva_j = \frac{CR_j}{PDC_j \cdot QDC_j + PM_j \cdot QM_j}, \qquad j = 7,8,9,10,11$$

6.3.8 Market equilibrium

The market equilibrium module consists of product market, labor market, capital market and foreign saving equilibria and the equilibrium in the saving and investment market. This model adopts the 'neoclassical' closure, which means that all the prices are perfectly elastic and are decided by the model. Factors such as capital are fully used and the labour force is in full employment. Savings are transferred into investment. The model employing these closure conditions is also called a 'saving-driven' model (Chang 2010).

Product market equilibrium implies that the supply of commodity j in a domestic market must equal the total domestic demand for commodity j. Specifically, the total domestic demand for commodity j includes intermediate input, household consumption, government purchase and investment of commodity j.

$$QQ_j = \sum_{i \in I} QINT_{ji} + QH_j + \overline{QG}_j + \overline{QINV}_j, \qquad j \in J$$

With the assumption of full employment, the labour market clears when the total labour demand equals the total available labour force. As it is assumed that the capital is fully used, the capital market clears when total capital demand is equal to the total available capital stock.

$$QLS = \overline{QLS}$$

$$\sum_{i \in I} QLD_i = \overline{QLS}$$

where

$\overline{QLS}$ - Total available labour force

$$QKS = \overline{QKS}$$

$$\sum_{i \in I} QKD_i = \overline{QKS}$$

where

$\overline{QKS}$ - Total available capital stock

Foreign savings refers to the difference between total value outflow (e.g., imports of goods and services) from the country and the total value inflow (e.g., exports and transfers from the rest of the world) to the country. As foreign savings are set exogenously, the equilibrating variable for this equation is the exchange rate (EXR). Through movements in EXR that affect import and export prices, equilibrium can be achieved. This foreign savings equilibrium equation can be expressed as

$$\overline{FSAV} = \sum_{j \in I} pwm_j \cdot QM_j - \sum_{i \in I} pwe_i \cdot QEX_i - transfr_{gf} \cdot EXR$$

where

$\overline{FSAV}$ - Savings in foreign country (in US$)

Equilibrium in the saving and investment market implies that the aggregate investment is equal to the total saving. The total saving consists of household, enterprise and government savings and savings in foreign countries. As this equation is mathematically unnecessary, a virtual variable, VBIS, is added. If the model is correct, the value of VBIS should be zero or close to zero.

$$ENIV = HSAV + ENTSAV + GSAV + EXR \cdot \overline{FSAV} + VBIS$$

Table 6.3 The Chinese carbon tax CGE model (summary)

Equations	
Production	
(1) $QNGO_i = \alpha_i^c[\delta_i^c QNG_i^{\rho_i^c} + (1-\delta_i^c)QO_i^{\rho_i^c}]^{\frac{1}{\rho_i^c}}$, $i \in I$	NG-oil mix function
(2) $\frac{QNG_i}{QO_i} = [\frac{\delta_i^c}{1-\delta_i^c} \cdot \frac{PF_8}{PF_9}]^{\frac{1}{1-\rho_i^c}}$, $i \in I$	Natural gas/oil input ratio
(3) $QFE_i = \alpha_i^f[\delta_i^f QNGO_i^{\rho_i^f} + (1-\delta_i^f)QC_i^{\rho_i^f}]^{\frac{1}{\rho_i^f}}$, $i \in I$	Fossil energy mix function
(4) $\frac{QNGO_i}{QC_i} = [\frac{\delta_i^f}{1-\delta_i^f} \cdot \frac{PF_7}{PNGO_i}]^{\frac{1}{1-\rho_i^f}}$, $i \in I$	NG-oil/coal input ratio
(5) $QEL_i = \alpha_i^s[\delta_i^s QTP_i^{\rho_i^s} + (1-\delta_i^s)QCE_i^{\rho_i^s}]^{\frac{1}{\rho_i^s}}$, $i \in I$	Electricity function

(6) $\frac{QTP_i}{QCE_i} = [\frac{\delta_i^s}{1-\delta_i^s} \cdot \frac{PF_{11}}{PF_{10}}]^{\frac{1}{1-\rho_i^s}},\ i \in I$	Thermal power/clean energy input ratio
(7) $QED_i = \alpha_i^e[\delta_i^e QFE_i^{\rho_i^e} + (1-\delta_i^e)QEL_i^{\rho_i^e}]^{\frac{1}{\rho_i^e}},\ i \in I$	Energy mix function
(8) $\frac{QFE_i}{QEL_i} = [\frac{\delta_i^e}{1-\delta_i^e} \cdot \frac{PEL_i}{PFE_i}]^{\frac{1}{1-\rho_i^e}},\ i \in I$	Fossil energy/electricity input ratio
(9) $QKED_i = \alpha_i^n[\delta_i^n QKD_i^{\rho_i^n} + (1-\delta_i^n)QED_i^{\rho_i^n}]^{\frac{1}{\rho_i^n}},\ i \in I$	Capital-energy mix function
(10) $\frac{QKD_i}{QED_i} = [\frac{\delta_i^n}{1-\delta_i^n} \cdot \frac{PED_i}{(1+tk)\cdot WK}]^{\frac{1}{1-\rho_i^n}},\ i \in I$	Capital/energy input ratio
(11) $QLKED_i = \alpha_i^m[\delta_i^m QLD_i^{\rho_i^m} + (1-\delta_i^m)QKED_i^{\rho_i^m}]^{\frac{1}{\rho_i^m}},\ i \in I$	Labour-capital-energy mix function
(12) $\frac{QLD_i}{QKED_i} = [\frac{\delta_i^m}{1-\delta_i^m} \cdot \frac{PKED_i}{(1+tl)\cdot WL}]^{\frac{1}{1-\rho_i^m}},\ i \in I$	Labour/capital-energy input ratio
(13) $QINT_{ji} = \alpha_{ji} \cdot QA_i,\ i \in I, j \in I$	Intermediate input function
(14) $QA_i = \sum_{j=1}^{6} QINT_{ji} + QLKED_i,\ i \in I$	Aggregate output function
Prices	
(15) $PF_j = (1 + tcva_j) \cdot PQ_j,\ j = 7,8,9,10,11$	Price of energy type j
(16) $PNGO_i \cdot QNGO_i = PF_9 \cdot QNG_i + PF_8 \cdot QO_i,\ i \in I$	Price of NG-oil mix
(17) $PFE_i \cdot QFE_i = PNGO_i \cdot QNGO_i + PF_7 \cdot QC_i,\ i \in I$	Price of fossil energy mix
(18) $PEL_i \cdot QEL_i = PF_{10} \cdot QTP_i + PF_{11} \cdot QCE_i,\ i \in I$	Price of electricity mix
(19) $PED_i \cdot QED_i = PFE_i \cdot QFE_i + PEL_i \cdot QEL_i,\ i \in I$	Price of energy mix
(20) $PKED_i \cdot QKED_i = (1 + tk) \cdot WK \cdot QKD_i + PED_i \cdot QED_i,$ $i \in I$	Price of capital-energy mix
(21) $PLKED_i \cdot QLKED_i = (1 + tl) \cdot WL \cdot QLD_i + PKED_i \cdot$ $QKED_i,\ i \in I$	Price of labour-capital-energy mix
(22) $PA_i \cdot QA_i = \sum_{j=1}^{6}(QINT_{ji} \cdot PQ_j) + PLKED_i \cdot QLKED_i,\ i \in$ I	Aggregate producer price
(23) $PM_j = pwm_j \cdot (1 + tm_j) \cdot EXR,\ j \in J$	Price of imports
(24) $PEX_i = pwe_i \cdot EXR,\ i \in I$	Price of exports
(25) $PA_i \cdot QA_i = PDA_i \cdot QDA_i + PEX_i \cdot QEX_i,\ i \in I$	Composite price in sector i
(26) $PQ_j \cdot QQ_j = PDC_j \cdot QDC_j + PM_j \cdot QM_j,\ j \in J$	Sale price of commodity j
(27) $QDC_j = \sum_i IDENT_{ij} \cdot QDA_i$	Quantity conversion
(28) $PDC_j = \sum_i IDENT_{ij} \cdot PDA_i$	Price conversion
Income	
(29) $YH = WL \cdot QLS + shif_{hk} \cdot WK \cdot QKS + transfr_{hg} +$ $transfr_{he} + shif_{hg} \cdot CR$	Household income
(30) $YENT = (1 - shif_{hk}) \cdot WK \cdot \overline{QKS} + transfr_{eg} - transfr_{he}$	Enterprise income
(31) $YG = \sum_{i \in I}(tl \cdot WL \cdot QLD_i + tk \cdot WK \cdot QKD_i) + ti_h \cdot YH +$ $ti_{ent} \cdot YENT + \sum_{j \in I}(tm_j \cdot pwm_j \cdot QM_j \cdot EXR) + (1 - shif_{hg}) \cdot$ $CR + transfr_{gf} \cdot EXR$	Government income
(32) $GDP = \sum_{j \in J}(QH_j + \overline{QG}_j + +\overline{QINV}_j - QM_j) + \sum_{i \in I} QEX_i$	Real GDP
(33) $\overline{PGDP} \cdot GDP = \sum_{j \in J} PQ_j \cdot (QH_j + \overline{QINV}_j + QG_j) +$ $\sum_{i \in I} PEX_i \cdot QEX_i - \sum_{j \in J} PM_j \cdot QM_j + \sum_{j \in J} tm_j \cdot pwm_j \cdot$ $QM_j \cdot EXR$	Nominal GDP

Expenditure	
(34) $PQ_j \cdot QH_j = shrh_j \cdot mpc \cdot (1 - ti_h) \cdot YH\ ,\ j \in J$	Household consumption
(35) $EG = \sum_{j \in J} PQ_j \cdot \overline{QG}_j + transfr_{hg} + transfr_{eg}$	Government expenditure
Investment and capital formation	
(36) $HSAV = (1 - mpc) \cdot (1 - ti_h) \cdot YH$	Household saving
(37) $ENTSAV = (1 - ti_{ent}) \cdot YENT$	Enterprise saving
(38) $GSAV = YG - EG$	Government saving
(39) $EINV = \sum_{j \in J} PQ_j \cdot \overline{QINV}_j$	Total investment
Trade	
(40) $QA_i = \alpha_i^t [\delta_i^t QDA_i^{\rho_i^t} + (1 - \delta_i^t) QEX_i^{\rho_i^t}]^{\frac{1}{\rho_i^t}}\ ,\ i \in I$	CET function
(41) $\frac{QDA_i}{QEX_i} = (\frac{\delta_i^t}{1 - \delta_i^t} \cdot \frac{PEX_i}{PDA_i})^{\frac{1}{1 - \rho_i^t}}\ ,\ i \in I$	Export/domestic demand ratio
(42) $QQ_j = \alpha_j^q [\delta_j^q QDC_j^{\rho_j^q} + (1 - \delta_j^q) QM_j^{\rho_j^q}]^{\rho_j^q}\ ,\ j \in J$	Armington function
(43) $\frac{QDC_j}{QM_j} = (\frac{\delta_j^q}{1 - \delta_j^q} \cdot \frac{PM_j}{PDC_j})^{\frac{1}{1 - \rho_j^q}}\ ,\ j \in J$	Import/domestic supply ratio
Environment	
(44) $EM_7 = (\sum_{i \in I} QC_i + \overline{HE}_7) \cdot em_7 \cdot \mu_7$	Carbon emissions of coal sector
(45) $EM_8 = (\sum_{i \in I} QO_i + \overline{HE}_8) \cdot em_8 \cdot \mu_8$	Carbon emissions of oil sector
(46) $EM_9 = (\sum_{i \in I} QNG_i + \overline{HE}_9) \cdot em_9 \cdot \mu_9$	Carbon emissions of natural gas sector
(47) $CR_j = tc \cdot EM_j\ ,\ j = 7,8,9,10,11$	Carbon revenue of energy type j
(48) $tcva_j = \frac{CR_j}{PDC_j \cdot QDC_j + PM_j \cdot QM_j}\ ,\ j = 7,8,9,10,11$	Ad valorem tax rate of energy type j
Market equilibrium	
(49) $QQ_j = \sum_{i \in I} QINT_{ji} + QH_j + \overline{QG}_j + \overline{QINV}_j\ ,\ j \in J$	Commodity equilibrium
(50) $QLS = \overline{QLS}$	Full employment assumption
(51) $\sum_{i \in I} QLD_i = \overline{QLS}$	Labour market equilibrium
(52) $QKS = \overline{QKS}$	Capital fully used assumption
(53) $\sum_{i \in I} QKD_i = \overline{QKS}$	Capital market equilibrium
(54) $\overline{FSAV} = \sum_{j \in I} pwm_j \cdot QM_j - \sum_{i \in I} pwe_i \cdot QEX_i - transfr_{gf} \cdot EXR$	Foreign saving equilibrium
(55) $ENIV = HSAV + ENTSAV + GSAV + EXR \cdot \overline{FSAV} + VBIS$	Saving-investment equilibrium

Table 6.4 List of variables and parameters

Endogenous variables:	
PF_j	Price of energy type j
QNG_i	Input of natural gas in sector i
QO_i	Input of oil in sector i
$QNGO_i$	Input of NG-oil mix in sector i
$PNGO_i$	Price of NG-oil mix in sector i
QC_i	Input of coal in sector i
QFE_i	Price of fossil energy mix in sector i
PFE_i	Input of fossil energy mix in sector i
QTP_i	Input of thermal power in sector i
QCE_i	Input of clean energy in sector i
QEL_i	Input of electricity mix in sector i
PEL_i	Price of electricity mix in sector i
QED_i	Input of energy mix in sector i
PED_i	Price of energy mix in sector i
QKD_i	Input of capital in sector i
WK	Price of capital (the rental rate)
$QKED_i$	Input of capital-energy mix in sector i
$PKED_i$	Price of capital-energy mix in sector i
QLD_i	Input of labour in sector i
WL	Price of labour (wage rate)
$QLKED_i$	Input of labour-capital-energy mix in sector i
$PLKED_i$	Price of labour-capital-energy mix in sector i
QA_i	Aggregate output in sector i
PA_i	Aggregate producer price in sector i
QDA_i	Total domestic demand for commodity produced in sector i
PDA_i	Domestic price for commodity produced in sector i
QEX_i	Exports in sector i
PEX_i	Domestic price of exports in sector i (in RMB¥)
QQ_j	Total demand of commodity j in domestic market
PQ_j	Sale price of commodity j in domestic market
QDC_j	Total domestic demand for domestic commodity j
PDC_j	Demand price for commodity j produced and sold domestically
QM_j	Imports of commodity j
PM_j	Domestic price of imports of commodity j (in RMB¥)
YH	Household income
QLS	Labour supply
QKS	Capital supply
YENT	Enterprise pre-tax income
YG	Government income
GDP	Real gross domestic production of China
QH_j	Household consumption of commodity j (in quantity)
EXR	Exchange rate
EG	Government expenditure (in money)
HSAV	Household saving
ENTSAV	Enterprise saving

$GSAV$	Government saving
$EINV$	Total investment (in money)
EM_j	Carbon emissions of energy type j
CR_j	Carbon revenue of energy type j
$TCVA_j$	Ad valorem tax rate of energy type j
$QINT_{ji}$	Intermediate input of commodity j in sector i
$VBIS$	Visual variable
Exogenous variables:	
$\overline{QG}_j$	Government purchase of commodity j (in quantity)
$\overline{QINV}_j$	The quantity investment of commodity j
$\overline{FSAV}$	Saving in foreign country (in US$)
$\overline{HE}_j$	Household consumption of energy type j (in quantity)
$\overline{QLS}$	Total available labour force
$\overline{QKS}$	Total available capital stock
$\overline{PGDP}$	Price index of GDP
Parameters:	
ρ_i^c	Substitution parameter between natural gas and oil in sector i
ρ_i^f	Substitution parameter between NG-oil mix and coal in sector i
ρ_i^s	Substitution parameter between thermal power and clean energy in sector i
ρ_i^e	Substitution parameter between fossil energy and electricity in sector i
ρ_i^n	Substitution parameter between capital and energy in sector i
ρ_i^m	Substitution parameter between labour and capital-energy mix in sector i
ρ_i^t	Substitution parameter between domestic consumption and exports in sector i
ρ_j^q	Substitution parameter between domestic supply and imports of commodity j
α_i^c	Transforming coefficient in the NG-oil mix function of sector i
α_i^f	Transforming coefficient in the fossil energy mix function of sector i
α_i^s	Transforming coefficient in the electricity function of sector i
α_i^e	Transforming coefficient in the energy mix function of sector i
α_i^n	Transforming coefficient in the capital-energy mix function for sector i
α_i^m	Transforming coefficient in the labour-capital-energy mix function for sector i
α_i^t	Transforming coefficient in the CET function of sector i
α_j^q	Transforming coefficient in the Armington function of commodity j
δ_i^c	Share of natural gas in the NG-oil mix function of sector i
δ_i^f	Share of NG-oil mix in the fossil energy mix function of sector i
δ_i^s	Share of thermal power in the electricity function of sector i
δ_i^e	Share of fossil energy in the energy mix function of sector i
δ_i^n	Share of capital in the capital-energy mix function of sector i
δ_i^m	Share of labour in the labour-capital-energy mix function of sector i
δ_i^t	Share parameter in the CET function of sector i
δ_j^q	Share parameter in the Armington function of commodity j
α_{ji}	The intermediate input of commodity j for each unit of output in sector i
$ident_{ij}$	Elements of unit matrix
pwm_j	World price of imports of commodity j (in US$)
pwe_i	World price of exports in sector i (in US$)

$shif_{hg}$	Ratio of the carbon tax revenues redistributed to household
em_j	Carbon emissions coefficient of energy type j
μ_j	Conversion coefficient of energy type j
tc	Carbon tax rate
tk	Capital value-added tax rate
tl	Labour value-added tax rate
ti_h	Individual income tax rate
ti_{ent}	Enterprise income tax rate
tm_j	Import tariff rate of commodity j
$shif_{hk}$	Share of total capital income for household
$shrh_j$	Share parameter of household expenditure on commodity j
$transfr_{hg}$	Transfer payment from government to households
$transfr_{eg}$	Transfer payment from government to enterprises
$transfr_{he}$	Transfer payment from enterprises to households
$transfr_{gf}$	Net foreign borrowing
mpc	Marginal propensity to consume

6.4 Data for the CGE model

6.4.1 Theory and structure of the social accounting matrix

A social accounting matrix (SAM) is the matrix expressive form of the System of National Accounts[24] (Duan 2004; SNA). It is a square matrix consisting of a series of accounts for various agents, capturing disaggregated economic activities and their interactions in an economy (Xie 1995). Keuning (1994, p. 22) defines SAM as 'the presentation of a sequence of accounts in a matrix that elaborates the interrelationships between economic flows (and stocks), by adopting in each account the most relevant statistical unit and classification of these units'. The major data source for SAM is the I/O table. It is the cornerstone of the CGE model.

Each row and column in a SAM represents income and expenditure accounts respectively which must balance with each other. The matrix implies costs (including distributed earnings) exhaust revenues for producers, expenditures (including taxes and savings) are equal to incomes in the model, and demand equals supply of each commodity (Robinson et al. 1990). Table 6.5 provides a representative SAM framework. It consists of nine accounts: activities, commodities, labour, capital,

[24] The United Union SNA formulates four expression approaches for the national accounting: graphic approach, balance report approach, account balance sheet and matrix approach. The first two methods are the initial form, and the account balance sheet is the basic form while the matrix balance sheet is the advanced form of accounting (Duan 2004).

household, enterprise, government, saving-investment and foreign countries. As can be seen, a SAM not only includes standard I/O parts (i.e., the relationship between activities and commodities), but also contains information about two factors of production (labour and capital), four institutions (household, enterprise, government and foreign countries) and so on. The equilibrium conditions covered in this representative SAM are:

Total production by activity = total input of that activity;

Total domestic demand for each commodity = total domestic supply of that commodity;

Labour factor income = labour factor expenditure;

Capital factor income = capital factor expenditure;

Total household income = total household expenditure;

Enterprise income = enterprise expenditure;

Government income = government expenditure;

Total saving = total investment;

Foreign income = foreign expenditure.

Roberts (1994) argues that the main usefulness of the SAM approach is to bring together the accounts of various economic agents to examine their behaviour in a consistent framework. In this research, the core role of a SAM is to provide a balanced, closed and consistent data set for parameters calibration in a CGE model. Furthermore, the SAM in a CGE model can be used to analyse the economic structure. SAM not only provides a full picture of the whole economy at the macro level, but it also reflects the internal structure of the economy at the divided level. In addition, SAM is employed in doing comparison analysis of the model results. Considering SAM as the benchmark equilibrium, the results analysis of most of CGE models is to evaluate the impacts level by comparing the divergence of SAM in different scenarios (Duan 2004).

Table 6.5 A representative social accounting matrix

	1 Activities	2 Commodities	3 Labour	4 Capital	5 Household	6 Enterprise	7 Government	8 Saving-investment	9 Foreign countries	10 Total
1 Activities		Domestic supply							Exports	Total production
2 Commodities	Intermediate input				Household consumption		Government purchase	Fixed investment and changes in stock		Total demand
3 Labour	Labour value-added									Labour factor income
4 Capital	Capital value-added									Capital factor income
5 Household			Labour income	Capital income		Enterprise transfers to labour	Government transfers to household			Total household income
6 Enterprise				Capital income			Government transfers to enterprise			Enterprise income
7 Government	Indirect tax	Tariff			Personal income tax	Enterprise income tax			Net foreign borrowing	Government income
8 Saving-investment					Household saving	Enterprise Saving	Government saving		Net foreign saving	Total saving
9 Foreign countries		Imports								Foreign exchange expenditure
10 Total	Total input	Total supply	Labour factor expenditure	Capital factor expenditure	Total household expenditure	Enterprise expenditure	Government expenditure	Total investment	Foreign exchange income	

6.4.2 Construction of the social accounting matrix

Normally, there are three steps in constructing the SAM (Duan 2004). The first step is to construct a sector-assembled macro SAM, which provides a consistent macro economy framework. Then, according to the research purpose, the assembled sector is divided into several sectors to form a divided SAM. During the division process, the value of the unit in the macro SAM controls the value in the split vectors. Finally, if the accounts in the divided SAM are unbalanced, some assumptions or treatment technology, such as RAS, Maximun Cross Entrophy (MCE) etc., need to be employed to make them balance.

SAM starts with an I/O table. Based on the latest published 'Input-output Table of China in 2007' (http://www.iochina.org.cn/Download/xgxz.html) and completed by the *China Statistical Yearbook 2008*, a macro SAM of China in 2007 is constructed (Table 6.6). The meaning and data source for each unit of the macro SAM are further explained in Appendix 11. The macro SAM presented in Table 6.6 is a balanced SAM. As there is not too much difference between the row sum and the column sum in the original SAM and the author knows the comparative reliability of each data, the China 2007 SAM in this research is balanced by hand. This method also has been justified by Chang (2010).

Then, the activities and commodities accounts in the macro SAM are separated into eleven sectors to form a divided SAM (see Table 6.2 for sectors classification). Most of the data required for the divided SAM are obtained from the 'Input-output Table of China in 2007'. Meanwhile, the value of each unit in the macro SAM is considered as the sum of the spilt vectors and used to control the balance of the divided SAM. The final equilibrium of the divided SAM is adjusted manually as well.

Table 6.6 China social accounting matrix in 2007

	1 Activity	2 Commodity	3 Labour	4 Capital	5 Household	6 Enterprise	7 Government	8 Saving-investment	9 Foreign countries	10 Total
1 Activity		712697.18							106161.78	818858.96
2 Commodity	552815.15				96552.62		35190.92	110919.42		795478.11
3 Labour	110047.30									110047.30
4 Capital	117477.79									117477.79
5 Household			110047.30	8979.60		39641.20	9095.50			167763.60
6 Enterprise				108498.19			882.90			109381.09
7 Government	38518.72	1426.66			13997.58	8779.25			3466.68	66188.90
8 Saving-investment					57213.40	60960.64	21019.58		-28274.20	110919.42
9 Foreign countries		81354.26								81354.26
10 Total	818858.96	795478.11	110047.30	117477.79	167763.60	109381.09	66188.90	110919.42	81354.26	

Note: Unit = 1×10^8 RMB¥

Data source: constructed by the author

6.4.3 Parameters and exogenous variables

In addition to the data obtained from the SAM, parameters of the model need to be estimated. The econometric and calibration approaches are two alternative parameter estimation methods (Xie 1995). The econometric approach estimates the parameters of CGE models by using time series data in statistical methods (Jorgenson 1984). The calibration approach determines parameter values by using the equilibrium conditions of the model and the benchmark year equilibrium data set (Zhang 1996). Due to factors such as insufficient data, computing resources constraints and so on, the econometric approach has not been used regularly by CGE model builders (Adams & Higgs 1990). Mansur & Whalley (1984) compare these two approaches thoroughly and conclude that the calibration approach is simpler, much less demanding of data and easier to use than the econometric approach. In practice, using single-observation data for parameters specification is very common in CGE modelling (Roberts 1994).

Therefore, due to the lack of time series data in China, a calibration approach is applied in this research to estimate some parameters. The parameters that need to be calibrated by the divided SAM include the share parameters and transform coefficients in all the CES production functions, CET function and Armington function, I/O coefficient, tax rates, share parameters of the income and expenditure, transfer payments, import and export prices and MPC. In addition, some exogenous variables such as foreign savings, total available labour force, total available capital stock etc. are also defined as parameters in the Generalized Algebraic Modeling System (GAMS)[25] and need to be calibrated before the model is used for simulation.

Moreover, parameters whose values cannot be calibrated by the SAM are then obtained from a search of the literature or set arbitrarily following Adams & Higgs (1990). Some parameters, including the substitution parameters in all the CES production functions, CET function and Armington function, carbon emissions coefficient and conversion efficient of energy types, are set exogenously based on the literature. In particular, the carbon tax rate and ratio of carbon tax revenue redistributed to households are set by the researcher according to the different policy

[25] This is one kind of software for solving CGE models. It will be discussed in section 6.5.

scenarios. Appendix 12 lists the data source for all the parameters in the Chinese carbon tax CGE model. The value of the exogenous parameters is given in Appendix 13. Particularly, since ‘clean energy’ is defined as electricity produced from renewable sources, including hydropower, nuclear power and wind power, substitution with thermal power is only limited due to a lack of capacity in the renewable industry. It is assumed that the capacity of renewable industry can be increased and, therefore, the elasticity between clean energy and thermal power is set fairly high at 10 following Wissema & Dellink (2007).

6.5 The CGE model software solution

Developments in computing technology have increasingly provided more efficient computer software for solving CGE models. For example, the non-linear GAMS developed by the World Bank, the General Equilibrium Modelling Package (GEMPACK) developed at Monash University in Australia (Harrison & Pearson 1996) and the Mathematical Programming System for General Equilibrium (MPSGE) (Rutherford 1987). Furthermore, it is suggested that MATLAB (Zhang et al. 2002), Eviews (Essama-Nssah 2004) and even Excel (Peng 2009) could also provide solutions for CGE models. The carbon tax CGE model in this research is solved with the widely distributed programming package GAMS.

Two steps are included in the solution process (Zhang 1996). The first step is to write the computer codes in GAMS programming language. The code starts by declaring and defining the sets, parameters and benchmark variables used, and assigning tables, some parameters and initial values for benchmark variables, then calibrating relative parameters, followed by declaring and defining all the variables and equations, and mathematically describing all the equations. The code ends with the bounds and initial values of the variables, model statement and output-generating statements. This phase of the process is independent of the solution algorithm. The second step is to use the MCP (Mixed Complementary Problem) solver Miles, which was developed by Thomas Rutherford to solve the model numerically (GAMS Development Corporation 2010). This solver of non-linear complementarity problems and non-linear systems of equations suits the CGE model in this research.

Due to the reliance on exogenous elasticity values and a single base-year observation, the parameters estimated above inevitably have errors or contain uncertainty. So, sensitivity analyses on key elasticities, including the substitution elasticises between energy types, and substitution elasticities in CET and Armington functions of energy sectors, are conducted to test the robustness of the simulation results to the changes in parameters. The CGE model passes the tests of efficiency and consistency, and generates reasonable results, so it can be used for effective simulation.

6.6 Conclusion

The methodology used to explore the suitability of using a carbon tax to reduce carbon emissions in China (research Q3) has been provided in this chapter. A CGE model has a clear structure of the micro-economy and linkages between macroeconomic and microeconomic variables. Thus it is the most appropriate approach to simulate the economy-wide effects of a carbon tax in China. Apart from justifying the use of a CGE approach and a review of the existing carbon tax CGE models, this chapter provided the assumptions, equations and data to be used in the CGE model constructed. The Chinese carbon tax CGE model allows us to simulate the impact of a carbon tax in China in a general equilibrium manner, including the environmental effect, macroeconomic impacts, sectoral effects and energy consumption structure effects, thereby addressing research Q3 (*Is carbon tax a suitable policy for reducing carbon emissions in China?*). The next chapter will present the simulation results.

Chapter 7 CGE model results and analysis

7.1 Introduction

In this chapter the static multi-sectoral carbon tax CGE model of the Chinese economy, which has been described and calibrated in Chapter 6, will be used to simulate the impact of a carbon tax in China under different carbon tax rates, including the environmental, macroeconomic, sectoral and energy consumption structure effects. Meanwhile, the cushion effects of the complementary policy (i.e., subsidizing households accompanying the carbon tax) will be assessed. Thereby the consequences of using a carbon tax policy in China can be explored, and the findings will address research Q3 (*Is carbon tax a suitable policy for reducing carbon emissions in China?*).

The rest of this chapter is organized as follows. Section 7.2 will describe the simulation scenarios to be used in this Chinese carbon tax CGE model and explain the fuel-specific tax rates. The main simulation results of the CGE model will be presented in the next four sections. Sections 7.3 to 7.6 will illustrate the environmental, macroeconomic, sectoral and energy consumption structure effects, respectively, of a carbon tax in China in two comparative scenarios with different carbon tax rates. A comparison with similar studies, a discussion of the suitability of using a carbon tax in China and some policy implications for implementing a carbon tax in China will be presented in section 7.7.

7.2 Simulation scenarios and fuel-specific tax rates

The impact of a carbon tax is illustrated by a comparison of situations with and without a carbon tax. The baseline scenario, the normal Chinese economy system in the absence of a carbon tax, will be constructed first. Thereafter, two scenarios, an independent carbon tax scenario and a carbon tax recycling scenario, will be computed to assess the impact of a carbon tax in China. As a carbon tax is assumed to be the only shock to the economic system, the 'independent carbon tax scenario' is defined as all carbon tax revenue becoming government fiscal revenue. The 'carbon recycling scenario' means that all the revenue from a carbon tax is recycled to households as a subsidy to consumers, and the fiscal revenue of government is neutral. In section 6.2.3 it was argued that recycling would lower the net adverse effects of a carbon tax on the economy. So the tax recycling scenario in this research allows us to investigate the cushion effects of the complementary policy (i.e., lump-sum transfers to households) in China.

Six schemes are considered for the independent carbon tax scenarios listed in Table 7.1. Based on the price of certified emission reductions in the CDM market, which is currently around €13 (US$16.5) (Point Carbon 2011), the six schemes are designed on the basis of the following carbon tax rates: RMB¥50 (US$7.9), RMB¥100 (US$15.9), RMB¥150 (US$23.9), RMB¥200 (US$31.8), RMB¥250 (US$39.7) and RMB¥300 (US$47.7) per tonne of carbon. Since the trend of the effects of carbon tax recycling can be sufficiently observed in two schemes, only RMB¥100/tC and RMB¥200/tC are simulated for the recycling scenario.

Table 7.1 Scenarios for CGE model simulation

Scenarios	Explanation
Baseline	China's economic system operates without carbon tax.
Independent carbon tax scenario	The revenue from a carbon tax is used as government fiscal revenue. Six schemes are considered according to different carbon tax levels per tonne of carbon: RMB¥50, RMB¥100, RMB¥150, RMB¥200, RMB¥250 and RMB¥300.
Carbon tax recycling scenario	All the revenue from a carbon tax is redistributed to households as a subsidy, and the government fiscal revenue keeps neutral. The carbon tax is levied at RMB¥100/tC and RMB¥200/tC.

As the carbon tax is levied on the CO_2 emissions of the three kinds of fossil energy, Table 7.2 converts the carbon taxes into fuel-specific ad valorem tax rates. It can be seen that fuel-specific tax rates differ among different types of fossil energy although at the same carbon tax rate. According to the function mentioned in section 6.3.7, the fuel-specific tax rate depends on the carbon content, price and domestic demand of fuel in the absence of carbon tax. As a result, the ad valorem tax rate for coal is the highest, natural gas is the second and oil comes the third. Since it is assumed in this model that the producers intend to fully pass the impact of the carbon price on to the consumers, these fuel-specific tax rates in turn increase the price of coal, natural gas and oil at the same rate respectively, which then lead to the changes in various factors of the whole economy system.

Table 7.2 Carbon taxes and fuel-specific tax rates

Carbon tax RMB¥/tC	0	50	100	150	200	250	300
Coal-specific tax rate (%)	0	25.287	50.574	75.862	101.149	126.436	151.723
Oil-specific tax rate (%)	0	1.546	3.091	4.637	6.183	7.729	9.274
Natural gas-specific tax rate (%)	0	3.440	6.879	10.319	13.758	17.198	20.638

7.3 The environmental effect of carbon tax in China

The environmental effect of the carbon tax is the key variable. According to the economic theory, a carbon tax would increase the price of fossil energy, which leads to a decrease in carbon-based energy consumption and, consequently, to a decline in related production and, therefore, to reductions in CO_2 emissions. To what extent a carbon tax can reduce CO_2 emissions in China needs to be estimated by some quantitative analysis, which in this research is the CGE model. This section will present the simulation results of environmental effects with different carbon tax rates in China under the independent carbon tax scenario and carbon tax recycling scenario, respectively.

7.3.1 The independent carbon tax scenario

The results in Table 7.3 show that only a small carbon tax rate of RMB¥50/tC could reduce the total CO_2 emissions by 6.301%. Carbon tax rates of RMB¥100/tC, RMB¥150/tC, RMB¥200/tC and RMB¥250/tC could result in a reduction of CO_2 emissions of 10.981%, 14.640%, 17.609% and 20.083% respectively. More than a 22% decrease of CO_2 emissions could be achieved by a carbon tax of RMB¥300/tC. As the carbon tax gets higher, the total CO_2 emissions decrease, but at a decreasing rate, indicating that the marginal effect of the tax in mitigating CO_2 emissions is getting smaller. For example, 6.301% CO_2 emissions reductions could be achieved by a carbon tax of RMB¥50/tC, but increasing the carbon tax by another RMB¥50 can only further reduce the CO_2 emissions by 4.680%. This finding can be more directly observed from Figure 7.1. It appears that the curves for all the sectoral CO_2 emissions and total CO_2 emissions are quadratic, which implies that the marginal environmental effect of the tax is diminishing. This is because even though a carbon tax would impel people to change their behaviors, as the tax getting infinate high, the consumption of fossil energy thus the total CO_2 emissions could not be zero.

Table 7.3 Percentage changes of carbon emissions in the independent carbon tax scenario compared with the baseline scenario under different carbon tax rates

Carbon tax RMB¥/tC	0	50	100	150	200	250	300
CO_2 emissions from coal sector (%)	0	-7.942	-13.831	-18.427	-22.148	-25.241	-27.868
CO_2 emissions from oil sector (%)	0	0.629	1.146	1.578	1.944	2.254	2.519
CO_2 emissions from natural gas sector (%)	0	-2.951	-5.747	-8.386	-10.874	-13.218	-15.428
Total CO_2 emissions (%)	0	-6.301	-10.981	-14.640	-17.609	-20.083	-22.189

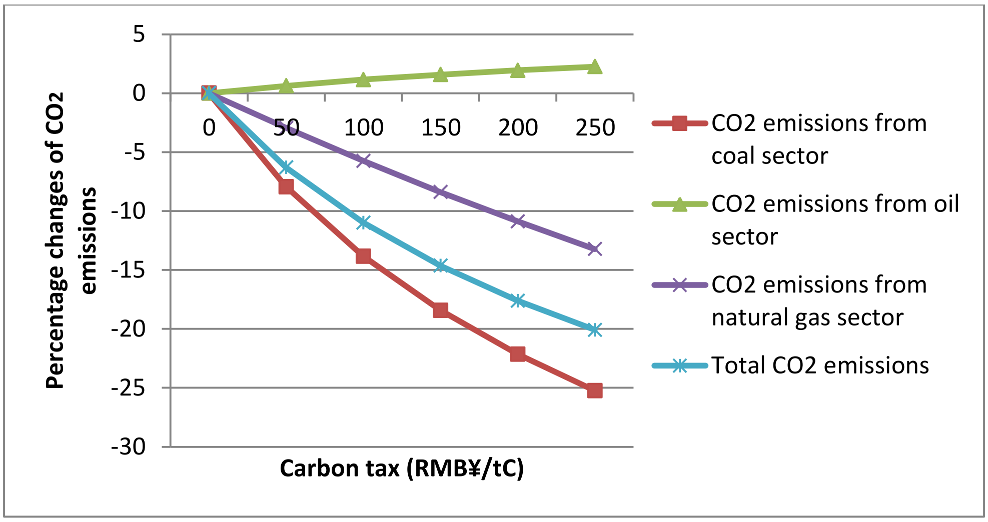


Figure 7.1 Percentage changes of carbon emissions in the independent carbon tax scenario compared with the baseline scenario under different carbon tax rates

Moreover, of the three fossil energy sectors, coal contributes to the largest CO_2 reductions and natural gas comes second, while oil has increased CO_2 emissions. This is due to the varied fuel-specific tax rates and different substitution elasticities between energy types. As mentioned in section 6.4.3, natural gas and oil are alternatives (substitution elasticity equals 2) and the fuel-specific tax rate of natural gas is greater than that for oil. So, after a carbon tax is imposed the natural gas becomes relatively more expensive than oil. Producers then would partly switch from natural gas to oil, which leads to a decrease in the total consumption of natural gas and an increase in the total consumption of oil. Thereafter, the total production of natural gas would be negatively affected and the oil production positively affected. As a consequence, CO_2 emissions from natural gas decrease and increase from the oil sector. Coal is the substitute for the NG-oil energy mix (substitution elasticity equals 0.5). The relatively large increase in the coal price, due to the high coal-specific tax rate, reduces the consumption of coal and meanwhile leads to the switch to other forms of energy. It is, therefore, not surprising that the CO_2 emissions from the coal sector decrease significantly.

7.3.2 The carbon tax recycling scenario

In the carbon tax recycling scenario the changes of sectoral CO_2 emissions and of total CO_2 emissions are similar to those in the independent carbon tax scenario. The CO_2 emissions from the coal and natural gas sectors decrease, while those from the oil sector increase slightly. The reason is the same as that for the independent carbon tax scenario (section 7.3.1). However, in the recycling scenario the amounts of CO_2 emissions from the three sectors are slightly larger than that in the independent carbon tax scenario. As can be seen from Table 7.4, at the carbon tax rate of RMB¥100/tC, the CO_2 emissions drop by 12.774% and 5.200% in the coal and natural gas sectors respectively, less than the value of 13.831% in coal and 5.747% in natural gas under the independent carbon tax scenario. Moreover, the increase of CO_2 emissions in oil sector is 1.150%, which is larger than that of 1.146% for the independent carbon tax scenario. These results imply that the environmental effect of the carbon tax would be weakened by redistributing all the carbon tax revenue to households.

Table 7.4 Comparison of the percentage changes of carbon emissions in the independent carbon tax scenario and carbon tax recycling scenario

	BAU	**Independent carbon tax scenario**	**Carbon tax recycling scenario**	**Independent carbon tax scenario**	**Carbon tax recycling scenario**
Carbon tax RMB¥/tC	**0**	**100**	**100**	**200**	**200**
CO_2 emissions from coal sector (%)	0	-13.831	-12.774	-22.148	-20.746
CO_2 emissions from oil sector (%)	0	1.146	1.150	1.944	1.985
CO_2 emissions from natural gas sector (%)	0	-5.747	-5.200	-10.874	-9.896
Total CO_2 emissions (%)	0	-10.981	-10.141	-17.609	-16.490

7.4 The macroeconomic impacts of carbon tax in China

The impacts of a carbon tax on the Chinese macro-economy in both the independent carbon tax scenario and the carbon tax recycling scenario are computed on fifteen macroeconomic variables (Tables 7.5 and 7.6). They are all real variables as the carbon tax is the only shock to the economy and the change of price is due to the tax rather than any other factors. Some of the variables are estimated from quantities, i.e. GDP, household consumption, total consumption, import, export, total demand and total supply, while some variables are estimated in values, i.e. household income, enterprise income, government income, government expenditure, household saving, enterprise saving, government saving and investment. However since the prices are assumed to be constant (section 6.4.3, SAM calibration), percentage change in quantity will be the same as percentage change in value. The following illustrates the major results of the two scenarios respectively.

7.4.1 The independent carbon tax scenario

Table 7.5 presents the percentage changes of the fifteen macroeconomic variables in the independent carbon tax scenario compared with the baseline scenario under six different carbon tax rates.

Table 7.5 Percentage changes of macroeconomic variables in the independent carbon tax scenario compared with the baseline scenario under different tax rates.

Carbon tax RMB¥/tC	0	50	100	150	200	250	300
GDP (%)	0	-0.320	-0.613	-0.884	-1.137	-1.374	-1.599
Household income (%)	0	-0.450	-0.866	-1.257	-1.625	-1.974	-2.307
Enterprise income (%)	0	-0.599	-1.179	-1.747	-2.307	-2.860	-3.410
Government income (%)	0	4.520	8.597	12.376	15.940	19.340	22.611
Household consumption (%)	0	-0.880	-1.684	-2.429	-3.124	-3.777	-4.394
Government expenditure (%)	0	0.233	0.454	0.664	0.867	1.063	1.253
Total consumption (%)	0	-0.645	-1.235	-1.780	-2.289	-2.768	-3.221
Household saving (%)	0	-0.450	-0.866	-1.257	-1.625	-1.974	-2.307
Enterprise saving (%)	0	-0.599	-1.179	-1.747	-2.307	-2.860	-3.410
Government saving (%)	0	13.734	26.098	37.544	48.330	58.616	68.509
Investment (%)	0	0.831	1.601	2.321	3.001	3.645	4.258
Import (%)	0	0.252	0.468	0.656	0.821	0.968	1.099
Export (%)	0	-0.194	-0.360	-0.505	-0.633	-0.746	-0.847
Total demand (%)	0	-0.209	-0.404	-0.587	-0.762	-0.928	-1.087
Total supply (production) (%)	0	-0.204	-0.395	-0.575	-0.746	-0.910	-1.067

The results show that the imposition of a carbon tax would lead to GDP loss. With carbon tax rates of RMB¥50/tC, RMB¥100/tC, RMB¥150/tC, RMB¥200/tC, RMB¥250/tC and RMB¥300/tC, the real GDP decreases by 0.320%, 0.613%, 0.884%, 1.137%, 1.374% and 1.599% respectively. The GDP losses are relatively modest compared with the large CO_2 emissions reductions. For example, a carbon tax rate of RMB¥50/tC results in 0.320% GDP loss, but the CO_2 emissions can be reduced by 6.312%. Moreover, the percentage change in GDP in every RMB¥50 carbon tax rate gets smaller as the carbon tax rate increases. This implies that the marginal effect of the tax on GDP is decreasing.

It can be seen from Table 7.5 that the impact of the carbon tax on enterprise income and saving, household income and saving are all negative. Given the assumption of an elastic capital rate, the capital rate decreases after the carbon tax is imposed, thereby decreasing total profit and further reduces enterprise income and enterprise saving. Simultaneously, the decrease in total profit lowers the profit distributed from enterprises to households. In addition, the decreased wage rate for labour leads to a decline in household income. As two of the most important components of household income contract, the total household income decreases. As a result, total household saving shrinks under a given individual tax rate and MPC.

The carbon tax increases government income, expenditure and saving. Specifically, the simulation results show that for a carbon tax of RMB¥50/tC and RMB¥300/tC, government income increases by 4.520% and 22.611% from the baseline respectively. This is because all the carbon tax revenue is assigned to the government's general revenue under the independent carbon tax scenario. The quantity of government consumption is determined exogenously in this model. Although the government expenditure increases due to the increase in prices, the government income increases more, which leads to the increase in government saving.

The carbon tax has a positive impact on total investment. It increases by 0.831% and 4.258% at a rate of RMB¥50/tC and RMB¥300/tC respectively. As the quantity of investment in each sector is set exogenously, the rise in total investment value can be explained by the increased prices of products caused by the tax. According to the 'saving-driven' closure principle in this model, total investment is transformed endogenously from total saving, which includes household, enterprise, government and foreign savings. While the foreign saving is fixed in the model, the increased total investment indicates that the increase in government saving is large enough to completely offset the reductions of household and enterprise savings.

Since the government consumption is considered exogenous, as mentioned earlier, the different carbon tax rates influence total consumption through their impact on household consumption. Household consumption is mainly decided by household disposable income and the level of consumer prices. Moreover, it is positively correlated with the former, while negatively correlated with the latter. As the household disposable income decreases and the consumer price increases, household consumption is reduced. Consequently, the total consumption decreases, at 0.645% and 3.221% for a carbon tax rate of RMB¥50/tC and RMB¥300/tC respectively.

It can be seen from the results that the impact of different carbon tax rates on total imports are all positive, while on total exports they are all negative. The possible reason is that the supply prices of products, especially the carbon-intensive products, increase greatly after the imposition of the carbon tax. Though the carbon tax also covers the imported coal, oil and natural gas, other imported commodities are exempted from the domestic carbon tax. Overall, the imported commodities become more competitive, so total imports increase and total exports decrease. At a carbon tax rate of RMB¥50/tC, total imports increase by 0.252% while total exports decline by 0.194%.

Since imposing a carbon tax increases the price of energy factors directly, the production sectors may reduce the input of energy, thereby a decline in the production sector may be observed and the total supply decreases. Total demand decreases as well due to reductions in intermediate input and household consumption. As shown in Table 7.5, the impacts of a carbon tax on total demand and total supply are relatively large. When the tax rate is RMB¥300/tC, total demand and total supply decrease by 1.087% and 1.067% respectively.

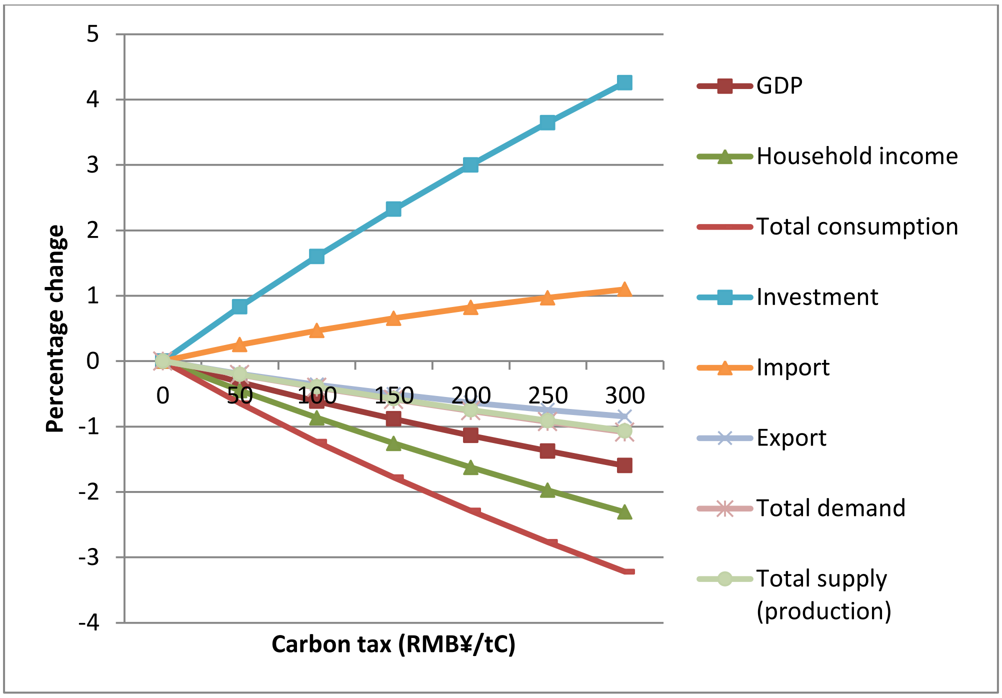


Figure 7.2 Changes in the main macroeconomic variables after carbon tax

Moreover, for every RMB¥50 increment in the carbon tax rate, it is found that the effects on all macroeconomic variables are lessening. Figure 7.2 presents the changes of main macroeconomic variables after the carbon tax is imposed. The curves for all main macroeconomic variables are not strictly linear. Instead, they are most likely quadratic, which imply that the marginal impacts of every RMB¥50 tax increase on the macro economy are diminishing. In other words, the macro economy tends to contract at a decreasing rate as the tax becomes higher.

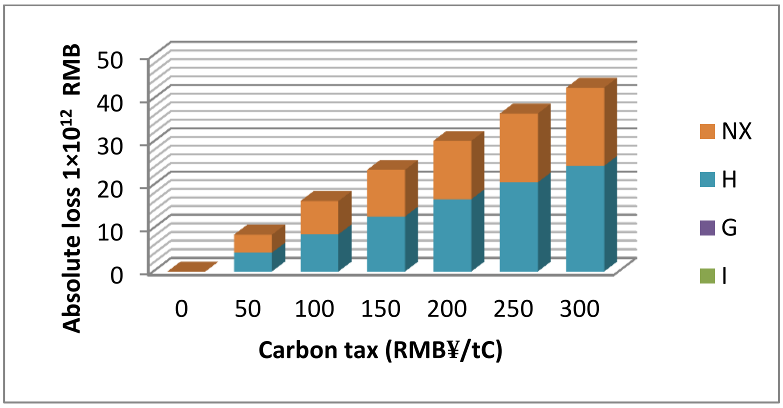


Figure 7.3 Contribution to the total absolute GDP loss

Finally, the contributions to the total absolute GDP loss are analysed and presented in Figure 7.3. As can be seen from the figure, among the four components of GDP, investment, government expenditure, household consumption and net exports (exports minus imports), the decreases in household consumption and net exports lead to a decrease in GDP. This implies that a carbon tax negatively affects GDP mainly through the adverse impacts on household consumption and net exports. The reduction of household consumption contributes more than half of the decrease in GDP, and the contribution rate is rising as the carbon tax increases. This shows the importance of the complementary policy of subsidizing households, which deserves careful consideration when designing the carbon tax program.

7.4.2 The carbon tax recycling scenario

Table 7.6 shows the changes in the fifteen macroeconomic variables at carbon tax rates of RMB¥100/tC and RMB200¥200/tC under the carbon tax recycling scenario.

Table 7.6 Comparison of the changes of macroeconomic variables in the independent carbon tax scenario and the carbon tax recycling scenario

	BAU	**Independent carbon tax scenario**	**Carbon tax recycling scenario**	**Independent carbon tax scenario**	**Carbon tax recycling scenario**
Carbon tax RMB¥/tC	**0**	**100**	**100**	**200**	**200**
GDP (%)	0	-0.613	-0.556	-1.137	-1.038
Household income (%)	0	-0.866	0.482	-1.625	1.480
Enterprise income (%)	0	-1.179	-1.179	-2.307	-2.307
Government income (%)	0	8.597	7.809	15.940	14.536
Household consumption (%)	0	-1.684	0.248	-3.124	0.493
Government expenditure (%)	0	0.454	0.454	0.867	0.867
Total consumption (%)	0	-1.235	0.181	-2.289	0.357
Household saving (%)	0	-0.866	0.482	-1.625	1.480
Enterprise saving (%)	0	-1.179	-1.179	-2.307	-2.307
Government saving (%)	0	26.098	8.895	48.330	17.312
Investment (%)	0	1.601	1.601	3.001	3.001
Import (%)	0	0.468	0.497	0.821	0.857
Export (%)	0	-0.360	-0.329	-0.633	-0.584
Total demand (%)	0	-0.404	-0.366	-0.762	-0.693
Total supply (production) (%)	0	-0.395	-0.357	-0.746	-0.678

For the most important macroeconomic variable, GDP, it can be seen from Table 7.6 that the reduction is 0.556% and 1.038% at the carbon tax rate of RMB¥100/tC and RMB¥200/tC respectively. They are less than in the independent carbon tax scenario at the same rates. Nevertheless, the differences are not very large, only 0.057% and 0.099% at the rates of RMB¥100/tC and RMB¥200/tC respectively. This implies that recycling all the carbon tax revenue to households could reduce the adverse impact of a carbon tax on GDP, even though the effect is relatively small. Moreover, for GDP, the effect of redistributing carbon tax to household is getting larger as the carbon tax rate increases.

The results show that household income, consumption and saving are positively affected by a carbon tax under carbon tax recycling scenario, in contrast to that in the independent carbon tax scenario. Household income increases by 0.482% at a carbon tax rate of RMB¥100/tC and by 1.480% at a carbon tax rate of RMB¥200/tC. This is because all the carbon tax revenue is redistributed to the households and becomes part of the household income. Therefore, when the income tax rate and MPC are unchanged, household consumption increases and household saving raises the same rate as household income. Clearly, these results indicate that the negative impact of a carbon tax on households can be totally offset by the lump-sum transfer to households and the transfer even could make the households better off with the carbon tax.

Government income still increases from the baseline but the growth rate is less than that in the independent carbon tax scenario because all the carbon tax revenue is redistributed to households. Due to the same price level and exogenous government consumption, government expenditure in both scenarios increases at the same rate. With the same level of government expenditure, government saving also increases but less than in the independent carbon tax scenario. As can be seen from Table 7.6, enterprise income, saving and total investment also change at the same rate in both scenarios because of the unchanged price level. As a result of the increased household consumption, total consumption rises by 0.181% and 0.357% at the carbon tax rate of RMB¥100/tC and RMB¥200/tC respectively.

The impact of carbon tax on total imports and exports are similar to those in the independent carbon tax scenario. But with the carbon tax being transferred to households, which stimulates total consumption, the increase of total imports from the baseline is larger than in the independent carbon tax scenario, while the decrease of total exports from the baseline is less. For example, at a carbon tax rate of RMB¥100/tC total imports rise by 0.468% and 0.497% and total exports decline by 0.360% and 0.329% for the independent carbon tax scenario and carbon tax recycling scenario respectively.

Total demand and total supply are also observed to have declined less than in the independent carbon tax scenario, even though they have still decreased from the baseline. At a carbon tax rate of RMB¥100/tC, total demand decreases by 0.366%, less than the 0.404% in the independent scenario. Total supply declines by 0.357%, compared with 0.395% in the independent scenario. These changes can also be attributed to the stimulated total consumption. Moreover, the results show that the difference between the independent scenario and the recycling scenario is larger at a carbon tax rate of RMB¥200/tC than at a rate of RMB¥100/tC.

Based on the observations from the fifteen macroeconomic variables, it can be concluded that subsidizing households could help to stimulate consumption and thus reduce the negative impacts of carbon tax on the whole economy, even though the effects are not very large. Furthermore, the cushion effects of subsidizing households are more obvious when the carbon tax is rising. This finding has an important policy implication, as it suggests that when the carbon tax gets higher, it becomes more worthwhile to subsidize households to reduce the adverse effects of the carbon tax.

7.5 The sectoral effects of carbon tax in China

The effects of the carbon tax will be different among sectors. After a carbon tax is imposed, people want to know which sectors suffer significantly and which sectors benefit from it. Section 7.5.1 presents the simulation results for these questions under the independent carbon tax scenario at different carbon tax rates. Section 7.5.2 shows the sectoral effects of a carbon tax under the carbon recycling scenario, with a comparison with the effects in the independent carbon tax scenario at carbon tax rates of RMB¥100/tC and RMB¥200/tC respectively.

7.5.1 The independent carbon tax scenario

Table 7.7 shows the impact of a carbon tax on prices of commodities in different sectors under the independent carbon tax scenario at different tax rates. As can be seen, prices of all the commodities increase by various degrees. At a same level of carbon tax, the largest increase in sale price happens in the coal sector. The price of coal rises by 25.287% at a carbon tax rate of RMB¥50/tC, and increases by as much as 151.723% at a rate of RMB300/tC. In contrast, the price of clean energy increases the least, only 0.131% and 0.976% at a rate of RMB¥50/tC and RMB¥300/tC respectively. These differing sectoral effects of prices can be explained as follows. As a result of the imposition of a carbon tax, the price of the target commodities, including coal, oil and natural gas, will be affected directly. Since other commodities use these three targeted commodities as inputs in their production, a carbon tax also affects the price of other commodities indirectly through a general equilibrium effect. Thus the sector that uses more target commodities as inputs would experience larger increases in prices. For instance, as the thermal power sector utilizes large amounts of fossil energy (e.g., coal) for producing electricity, the increase of the price in the thermal power sector is the second largest. Moreover, it is observed from Table 7.7 that the prices of commodities increase at decreasing rates as the carbon tax becomes higher, indicating that the marginal impact of the tax on prices of commodities is diminishing.

Table 7.7 Changes of the sale prices for products in different sectors under the independent carbon tax scenario

Carbon tax RMB¥/tC	0	50	100	150	200	250	300
Agriculture (%)	0	0.221	0.426	0.616	0.796	0.967	1.130
Heavy industry (%)	0	1.139	2.196	3.175	4.100	4.974	5.806
Light industry (%)	0	0.245	0.473	0.685	0.887	1.078	1.261
Transport and communication (%)	0	0.608	1.200	1.773	2.336	2.889	3.433
Construction (%)	0	0.746	1.440	2.086	2.699	3.280	3.835
Services (%)	0	0.289	0.564	0.823	1.073	1.314	1.547
Coal (%)	0	25.287	50.574	75.862	101.149	126.436	151.723
Oil (%)	0	1.546	3.091	4.637	6.183	7.729	9.274
Natural gas (%)	0	3.440	6.879	10.319	13.758	17.198	20.638
Thermal power (%)	0	4.776	9.314	13.621	17.791	21.832	25.765
Clean energy (%)	0	0.131	0.321	0.498	0.666	0.825	0.976

Theoretically, the carbon tax exerts a further negative impact on the sectoral production through the sectoral price effect. The sector with the larger price change declines more in production approximately. In response to the largest price change, the coal sector is expected to be the most severely affected sector in terms of production under a carbon tax. This is confirmed in Table 7.8 which shows that production from the coal sector falls by 12.108% at RMB¥50/tC and by 44.718% at RMB¥300/tC. Natural gas and thermal power are the sectors with the second largest decreases in output, while the production in agriculture and light industry only decreases slightly. However, as can be seen from Table 7.8, not all the industries are affected negatively by a carbon tax. The oil and clean energy sectors experience increases in production, even though their prices rise after the imposition of a carbon tax. This can be explained by the substitution effects in the production process. Oil is an alternative for natural gas and clean energy is an alternative for thermal power. They become relatively cheaper after a carbon tax is imposed. Thus producers substitute oil and clean energy for natural gas and thermal power respectively. The consumption of oil and clean energy increases, and stimulates the production of oil and clean energy. In addition, the increase of production in clean energy is very surprising and is most likely because the absolute production of clean energy is small at the baseline.

Table 7.8 Changes of production in different sectors under the independent carbon tax scenario

Carbon tax RMB¥/tC	**0**	**50**	**100**	**150**	**200**	**250**	**300**
Agriculture (%)	0	-0.028	-0.054	-0.079	-0.103	-0.126	-0.148
Heavy industry (%)	0	-1.423	-1.813	-2.178	-2.521	-2.846	-3.154
Light industry (%)	0	-0.118	-0.207	-0.273	-0.318	-0.347	-0.370
Transport and communication (%)	0	-0.326	-0.531	-0.683	-0.786	-0.841	-0.876
Construction (%)	0	-0.620	-1.129	-1.549	-1.895	-2.077	-2.406
Services (%)	0	-0.138	-0.228	-0.295	-0.341	-0.371	-0.395
Coal (%)	0	-12.108	-21.527	-29.234	-35.403	-40.526	-44.718
Oil (%)	0	2.712	5.171	7.43	9.529	11.496	13.324
Natural gas (%)	0	-7.066	-13.265	-18.812	-23.848	-28.479	-32.757
Thermal power (%)	0	-8.058	-15.32	-22.216	-27.325	-31.574	-35.431
Clean energy (%)	0	27.196	63.358	97.497	130.619	162.728	194.829

Household consumption changes differently among different sectors (Table 7.9). Under a carbon tax, household consumption decreases for all products, but especially for carbon-intensive products. The percentage decrease of household consumption for thermal power is the largest. As the carbon tax rate increases from RMB¥50/tC to RMB¥300/tC, the decrease in consumption of thermal power rises from 4.987% to more than 22%. The second largest decline is the consumption for coal and the third is the consumption for natural gas. Then follow oil, heavy industry, construction, transport and communication, services, light industry, agriculture and clean energy.

Table 7.9 Percentage changes of household consumption for different sectors in the independent carbon tax scenario under different tax rates

Carbon tax RMB¥/tC	0	50	100	150	200	250	300
Agriculture (%)	0	-0.229	-0.443	-0.645	-0.836	-1.017	-1.191
Heavy industry (%)	0	-1.571	-2.993	-4.295	-5.499	-6.619	-7.668
Light industry (%)	0	-0.693	-1.332	-1.929	-2.489	-3.019	-3.523
Transport and communication (%)	0	-1.051	-2.04	-2.977	-3.87	-4.727	-5.55
Construction (%)	0	-1.186	-2.271	-3.275	-4.21	-5.088	-5.915
Services (%)	0	-0.737	-1.421	-2.063	-2.669	-3.245	-3.795
Coal (%)	0	-3.219	-6.051	-8.583	-10.873	-12.963	-14.886
Oil (%)	0	-2.237	-4.274	-6.152	-7.899	-9.533	-11.071
Natural gas (%)	0	-2.678	-4.705	-6.605	-8.356	-10.004	-11.545
Thermal power (%)	0	-4.987	-9.298	-13.094	-16.483	-19.54	-22.321
Clean energy (%)	0	-0.137	-0.321	-0.491	-0.651	-0.804	-0.953

The imports and exports also change differently across different sectors (Tables 7.10 and 7.11). The imports in all sectors increase after a tax is imposed. As the tax rises, the imports in all sectors increase as well, though the rates of increase are declining. Not surprisingly, the carbon-intensive sectors of coal, thermal power, natural gas and oil are still the most seriously affected sectors. As can be seen from Table 7.10, the imports of coal, thermal power, natural gas and oil increase by as much as 9.805%, 6.737%, 5.158% and 2.206% at a carbon tax of RMB¥300/tC. The exports decrease in all the other sectors, except in the services sector. At carbon tax rates of RMB¥50/tC and RMB¥300/tC, the export in services sector increases by 1.219% and 4.895% respectively. This implies that the services sector becomes more competitive in the international market. The exports in the coal, thermal power, natural gas and oil sectors decrease significantly. The exports in other carbon-intensive sectors such as heavy industry, construction, and transport and communication decrease greatly as well. The changes of exports in agriculture and light industry are relatively small. In addition, the changes of both imports and exports in the clean energy sector are zero. This is because the imports and exports in this sector are assumed to be zero at the baseline.

Table 7.10 Changes of imports for sectors in the independent carbon tax scenario under different tax rates

Carbon tax RMB¥/tC	0	50	100	150	200	250	300
Agriculture (%)	0	0.031	0.043	0.053	0.060	0.065	0.067
Heavy industry (%)	0	0.257	0.511	0.760	0.994	1.216	1.428
Light industry (%)	0	0.126	0.241	0.345	0.443	0.532	0.619
Transport and communication (%)	0	0.162	0.412	0.551	0.682	0.768	0.847
Construction (%)	0	0.170	0.332	0.746	0.779	1.128	1.392
Services (%)	0	0.066	0.144	0.213	0.269	0.316	0.356
Coal (%)	0	1.981	3.785	5.448	6.994	8.441	9.805
Oil (%)	0	0.495	0.925	1.303	1.638	1.937	2.206
Natural gas (%)	0	0.977	1.892	2.760	3.589	4.387	5.158
Thermal power (%)	0	1.350	2.587	3.731	4.798	5.797	6.737
Clean energy (%)	0	0	0	0	0	0	0

Table 7.11 Changes of exports for sectors in the independent carbon tax scenario under different tax rates

Carbon tax RMB¥/tC	0	50	100	150	200	250	300
Agriculture (%)	0	-0.019	-0.034	-0.046	-0.055	-0.062	-0.067
Heavy industry (%)	0	-0.375	-0.745	-1.032	-1.219	-1.351	-1.433
Light industry (%)	0	-0.084	-0.112	-0.135	-0.154	-0.171	-0.332
Transport and communication (%)	0	-0.289	-0.431	-0.539	-0.612	-0.661	-0.685
Construction (%)	0	-0.104	-0.237	-0.342	-0.433	-0.513	-0.585
Services (%)	0	1.219	2.238	3.092	3.808	4.404	4.895
Coal (%)	0	-4.939	-9.745	-14.464	-19.127	-23.756	-28.366
Oil (%)	0	-1.325	-2.544	-3.679	-4.746	-5.757	-6.719
Natural gas (%)	0	-2.296	-4.339	-6.179	-7.848	-9.372	-10.771
Thermal power (%)	0	-3.457	-6.578	-9.425	-12.042	-14.46	-16.708
Clean energy (%)	0	0	0	0	0	0	0

In summary, the simulation results show that the carbon-intensive sectors would suffer most seriously from a carbon tax, while low-carbon or non-carbon sectors may benefit from it.

7.5.2 The carbon tax recycling scenario

The sectoral changes of production, household consumption, imports and exports under the carbon recycling scenario are shown in Tables 7.12 to 7.15 respectively. Compared with the results at the same carbon tax rate in the independent carbon tax scenario, production, household consumption, imports and exports increase in all the sectors, especially household consumption. After a carbon tax is imposed, all sectoral household consumption decreases greatly from the baseline, but they increase significantly from the baseline once the carbon tax revenue is redistributed to households. Moreover, it is noted that the positive effects of a recycling carbon tax become more obvious as a carbon tax increases. In addition, it seems that the carbon-intensive sectors benefit more from recycling the carbon tax revenue to households. For instance, household consumption for thermal power increases by 9.751% from the independent scenario to the recycling scenario at the tax rate of RMB¥100/tC.

Table 7.12 Comparison of the changes of production for different sectors in the independent carbon tax scenario and carbon tax recycling scenario

	BAU	**Independent carbon tax scenario**	**Carbon tax recycling scenario**	**Independent carbon tax scenario**	**Carbon tax recycling scenario**
Carbon tax RMB¥/tC	**0**	**100**	**100**	**200**	**200**
Agriculture (%)	0	-0.054	-0.035	-0.103	-0.067
Heavy industry (%)	0	-1.813	-1.749	-2.521	-2.051
Light industry (%)	0	-0.207	-0.199	-0.318	-0.264
Transport and communication (%)	0	-0.531	-0.502	-0.786	-0.622
Construction (%)	0	-1.129	-1.049	-1.895	-1.594
Services (%)	0	-0.228	-0.203	-0.341	-0.326
Coal (%)	0	-21.527	-19.198	-35.403	-30.31
Oil (%)	0	5.171	5.69	9.529	10.871
Natural gas (%)	0	-13.265	-11.28	-23.848	-20.489
Thermal power (%)	0	-15.32	-14.208	-27.325	-22.189
Clean energy (%)	0	63.358	65.832	130.619	135.572

Table 7.13 Comparison of the changes of household consumption for different sectors in the independent carbon tax scenario and carbon tax recycling scenario

	BAU	**Independent carbon tax scenario**	**Carbon tax recycling scenario**	**Independent carbon tax scenario**	**Carbon tax recycling scenario**
Carbon tax RMB¥/tC	**0**	**100**	**100**	**200**	**200**
Agriculture (%)	0	-0.443	0.074	-0.836	0.144
Heavy industry (%)	0	-2.993	0.225	-5.499	0.348
Light industry (%)	0	-1.332	0.123	-2.489	0.237
Transport and communication (%)	0	-2.04	0.170	-3.87	0.261
Construction (%)	0	-2.271	0.182	-4.21	0.291
Services (%)	0	-1.421	0.144	-2.669	0.250
Coal (%)	0	-6.051	0.414	-10.873	0.631
Oil (%)	0	-4.274	0.321	-7.899	0.453
Natural gas (%)	0	-4.705	0.354	-8.356	0.572
Thermal power (%)	0	-9.298	0.453	-16.483	0.821
Clean energy (%)	0	-0.321	0.056	-0.651	0.084

Table 7.14 Comparison of the changes of imports in the independent carbon tax scenario and carbon tax recycling scenario

	BAU	Independent carbon tax scenario	Carbon tax recycling scenario	Independent carbon tax scenario	Carbon tax recycling scenario
Carbon tax RMB¥/tC	**0**	**100**	**100**	**200**	**200**
Agriculture (%)	0	0.043	0.075	0.060	0.103
Heavy industry (%)	0	0.511	0.644	0.994	1.257
Light industry (%)	0	0.241	0.278	0.443	0.514
Transport and communication (%)	0	0.412	0.479	0.682	0.790
Construction (%)	0	0.332	0.338	0.779	0.788
Services (%)	0	0.144	0.168	0.269	0.311
Coal (%)	0	3.785	3.837	6.994	7.088
Oil (%)	0	0.925	0.973	1.638	1.729
Natural gas (%)	0	1.892	1.96	3.589	3.718
Thermal power (%)	0	2.587	2.715	4.798	5.038
Clean energy (%)	0	0	0	0	0

Table 7.15 Comparison of the changes of exports in the independent carbon tax scenario and carbon tax recycling scenario

	BAU	Independent carbon tax scenario	Carbon tax recycling scenario	Independent carbon tax scenario	Carbon tax recycling scenario
Carbon tax RMB¥/tC	**0**	**100**	**100**	**200**	**200**
Agriculture (%)	0	-0.034	-0.028	-0.055	-0.044
Heavy industry (%)	0	-0.745	-0.714	-1.219	-0.719
Light industry (%)	0	-0.112	-0.107	-0.154	-0.145
Transport and communication (%)	0	-0.431	-0.416	-0.612	-0.586
Construction (%)	0	-0.237	-0.209	-0.433	-0.381
Services (%)	0	2.238	3.848	3.808	6.537
Coal (%)	0	-9.745	-7.245	-19.127	-14.697
Oil (%)	0	-2.544	-1.792	-4.746	-3.267
Natural gas (%)	0	-4.339	-3.522	-7.848	-6.305
Thermal power (%)	0	-6.578	-5.307	-12.042	-9.521
Clean energy (%)	0	0	0	0	0

In summary, the negative impacts of a carbon tax on the sectors could be relieved to some extent by transferring the carbon tax revenue to households, even though the relief is relatively small. In addition, carbon tax recycling has a greater impact on the carbon-intensive sectors, especially at a higher carbon tax rate.

7.6 The impacts of carbon tax on energy consumption structure in China

According to the market mechanism, imposing a carbon tax on carbon energy will change the relative prices of commodities. Carbon-free or low-carbon-containing commodities and services become cheaper than those of high-carbon content. Such changes in the relative prices will lead to a shift away from high-carbon energy, and carbon-intensive commodities and services to carbon-free energy or low-carbon commodities and services. This will consequently change the energy consumption structure. Therefore, how a carbon tax could help improve the energy consumption structure in China is explored in this section, under both the independent carbon tax scenario and the carbon tax recycling scenario.

7.6.1 The independent carbon tax scenario

Tables 7.16 and 7.17 show the changes of input factors in different sectors under an independent carbon tax scenario at the carbon tax rates of RMB¥100/tC and RMB¥200/tC respectively. As can be observed, the changes of input factors are in different directions and at varied rates across sectors. The use of coal, natural gas and thermal power as input factors of production decreases in all sectors, while the use of clean energy increases among all sectors. Meanwhile, the utilization of the other three kinds of input factors (oil, capital and labour) rises in some sectors but declines in others. For oil, the different directional changes can be explained by the substitution effects between oil and natural gas and the production reduction effects in sectors. After the imposition of a carbon tax, sectors tend to use more oil as a substitute for natural gas in production. However, sectors release some oil due to the decreases in production. Therefore, if the substitution effect is large enough to offset the production reduction effect, the use of oil as an input factor increases in a sector; otherwise it decreases in that sector. For capital and labour, given that the total amounts of capital and labour available to the economy are fixed but are allowed to flow from one sector to another, the released capital and labour from some sectors have to be absorbed by other sectors.

It is worth noting that the carbon-intensive sectors are more likely to use low-carbon factors to substitute high-carbon factors, and capital or labour to substitute carbon

Table 7.16 Changes of input factors for sectors in the independent carbon tax scenario RMB¥100/tC

	Coal	Oil	Natural gas	Thermal power	Clean energy	Capital	Labour
Agriculture (%)	-19.994	-3.306	-10.039	-17.478	58.488	-2.623	-2.015
Heavy industry (%)	-15.302	2.511	-4.627	-14.484	64.238	1.302	2.845
Light industry (%)	-16.933	0.530	-6.470	-17.697	58.067	-2.387	-1.901
Transport and communication (%)	-18.289	-1.238	-8.114	-15.172	62.917	-0.188	-0.245
Construction (%)	-17.868	-0.739	0	-15.070	63.113	0.143	0.267
Services (%)	-18.012	-0.713	-7.626	-15.805	61.702	-0.579	-0.817
Coal (%)	-12.371	5.957	-1.420	-17.575	58.304	-0.732	6.665
Oil (%)	-16.989	1.062	-5.975	-14.642	63.936	0.739	2.553
Natural gas (%)	-17.788	0.762	-6.253	-15.221	62.824	0.050	0.200
Thermal power (%)	-11.373	7.299	-0.171	-2.123	87.979	1.543	8.014
Clean energy (%)	0	0	0	-39.369	16.445	0.518	1.029

Table 7.17 Changes of input factors for sectors in the independent carbon tax scenario RMB¥200/tC

	Coal	Oil	Natural gas	Thermal power	Clean energy	Capital	Labour
Agriculture (%)	-31.755	-6.065	-18.160	-34.515	126.015	-4.728	-3.694
Heavy industry (%)	-24.373	4.376	-9.063	-30.111	141.214	2.387	5.205
Light industry (%)	-27.198	0.464	-12.471	-34.866	124.802	-4.390	-3.541
Transport and communication (%)	-29.083	-2.375	-14.944	-31.157	137.602	-0.315	-0.368
Construction (%)	-28.407	-1.462	0	-30.989	138.181	0.276	0.489
Services (%)	-28.678	-1.462	-14.149	-32.098	134.356	-1.088	-1.528
Coal (%)	-20.174	9.972	-4.187	-34.456	126.218	-1.199	12.454
Oil (%)	-26.988	1.889	-11.230	-30.331	140.453	1.427	4.855
Natural gas (%)	-28.234	1.427	-11.632	-31.178	137.531	0.140	0.383
Thermal power (%)	-18.330	12.781	-1.740	-3.796	232.037	2.908	15.087
Clean energy (%)	0	0	0	-63.202	27.003	0.901	1.434

factors. For instance, at a carbon tax rate of RMB¥100/tC, heavy industry reduces the use of coal, natural gas and thermal power by 15.302%, 4.627% and 14.484% respectively, while increases in the use of oil, clean energy, capital and labour are by 2.511%, 64.238%, 1.302% and 2.845% correspondingly. Similar changes could be also observed in the high-carbon sectors of oil, natural gas and thermal power. In addition, capital and labour flow from low-carbon sectors to high-carbon sectors. As can be seen from Table 7.16, both the inputs of capital and labour are reduced in the agriculture, light industry and services sectors. The clean energy sector does not use coal, oil and natural gas, so the changes of these factors in the clean energy sector are zero. The clean energy sector uses more capital and labour to support the increase in production, which has been reported in section 7.5.1.

Moreover, comparing Table 7.17 with Table 7.16 shows that the changes of input factors are larger at a carbon tax rate of RMB¥200/tC than at RMB¥100/tC, indicating that the energy consumption structure is changing as the carbon tax increases. At a carbon tax rate of RMB¥200/tC, the use of clean energy as an input increases by as much as 141.214% in heavy industry though from a relatively low amount. All-in-all, these changes of input factors imply that a carbon tax leads to a shift from high-carbon factors towards low-carbon and non-carbon factors, away from carbon-related factors towards capital and labour.

7.6.2 The carbon tax recycling scenario

Tables 7.18 and 7.19 present the changes of input factors for sectors under the carbon tax recycling scenario at the carbon tax rates of RMB¥100/tC and RMB¥200/tC respectively. It can be seen from the tables that the substitution effect, shifting from high-carbon factors towards low-carbon or non-carbon factors, is less than that in the independent carbon tax scenario at the same carbon tax rate. This implies that the effect of a carbon tax on improving the energy consumption structure is weakened by the lump-sum transfer to households. For instance, heavy industry uses less clean energy, oil, capital and labour but uses more coal, natural gas and thermal power as inputs in the recycling scenario than in the independent scenario. In addition, the sectoral changes of input factors between the independent scenario and the recycling scenario are larger at the carbon tax rate of RMB¥200/tC than at RMB¥100/tC, which indicates that the negative impact of recycling carbon tax on improving energy consumption structure is also increasing as the carbon tax rises.

In short, the carbon tax has been suggested as being able to improve the energy consumption structure in China by shifting from high-carbon factors towards low-carbon or non-carbon factors. The energy consumption structure effects also get more obvious as the carbon tax increases. However, the positive impact of a carbon tax in improving the energy consumption structure could be weakened when the carbon tax revenue is redistributed to households, and the negative effect is more apparent when the carbon tax rate becomes higher.

Table 7.18 Comparison of the changes of input factors for sectors in the independent carbon tax scenario and carbon tax recycling scenario under tax rate of RMB¥100/tC

	Coal		Oil		Natural gas		Thermal power		Clean energy		Capital		Labour	
	I	R	I	R	I	R	I	R	I	R	I	R	I	R
Agriculture (%)	-19.994	-18.483	-3.306	-3.003	-10.039	-9.131	-17.478	-15.737	58.488	52.123	-2.623	-2.387	-3.701	-1.831
Heavy industry (%)	-15.302	-14.142	2.511	2.294	-4.627	-4.168	-14.484	-12.964	64.238	57.131	1.302	1.183	5.213	2.585
Light industry (%)	-16.933	-15.634	0.530	0.511	-6.470	-5.839	-17.697	-15.939	58.067	51.759	-2.387	-2.168	-3.547	-1.724
Transport and communication (%)	-18.289	-16.905	-1.238	-1.119	-8.114	-7.366	-15.172	-13.598	62.917	55.985	-0.188	-0.172	0.369	-0.226
Construction (%)	-17.868	-16.516	-0.739	-0.666	0	0	-15.070	-13.505	63.113	56.153	0.143	0.129	0.490	0.243
Services (%)	-18.012	-16.647	-0.713	-0.640	-7.626	-6.917	-15.805	-14.184	61.702	54.927	-0.579	-0.525	-1.531	-0.741
Coal (%)	-12.371	-11.400	5.957	5.470	-1.420	-1.193	-17.575	-15.842	58.304	51.934	-0.732	-0.673	12.476	6.044
Oil (%)	-16.989	-15.705	1.062	0.968	-5.975	-5.411	-14.642	-13.110	63.936	56.866	0.739	0.668	4.864	2.311
Natural gas (%)	-17.788	-16.445	0.762	0.691	-6.253	-5.670	-15.221	-13.647	62.824	55.897	0.050	0.043	0.383	0.180
Thermal power (%)	-11.373	-10.496	7.299	6.668	-0.171	-0.071	-2.123	-1.935	87.979	77.041	1.543	1.398	15.114	7.262
Clean energy (%)	0	0	0	0	0	0	-39.369	-36.246	16.445	15.099	0.518	0.474	1.435	0.960

Table 7.19 Comparison of the changes of input factors for sectors in the independent carbon tax scenario and carbon tax recycling scenario under tax rate of RMB¥200/tC

	Coal		Oil		Natural gas		Thermal power		Clean energy		Capital		Labour	
	I	R	I	R	I	R	I	R	I	R	I	R	I	R
Agriculture (%)	-31.755	-29.792	-6.065	-5.550	-18.160	-16.662	-34.515	-31.189	126.015	112.146	-4.728	-4.340	-2.015	-3.380
Heavy industry (%)	-24.373	-22.852	4.376	4.042	-9.063	-8.199	-30.111	-26.963	141.214	125.175	2.387	2.184	2.845	4.764
Light industry (%)	-27.198	-25.463	0.464	0.507	-12.471	-11.318	-34.866	-31.520	124.802	111.126	-4.390	-4.014	-1.901	-3.229
Transport and communication (%)	-29.083	-27.277	-2.375	-2.154	-14.944	-13.667	-31.157	-27.961	137.602	122.098	-0.315	-0.294	-0.245	-0.351
Construction (%)	-28.407	-26.644	-1.462	-1.319	0	0	-30.989	-27.804	138.181	122.584	0.276	0.250	0.267	0.448
Services (%)	-28.678	-26.891	-1.462	-1.311	-14.149	-12.923	-32.098	-28.862	134.356	119.322	-1.088	-0.991	-0.817	-1.393
Coal (%)	-20.174	-18.839	9.972	9.274	-4.187	-3.583	-34.456	-31.165	126.218	112.220	-1.199	-1.121	6.665	11.351
Oil (%)	-26.988	-25.317	1.889	1.738	-11.230	-10.232	-30.331	-27.177	140.453	124.515	1.427	1.292	2.553	4.410
Natural gas (%)	-28.234	-26.490	1.427	1.301	-11.632	-10.618	-31.178	-27.991	137.531	122.007	0.140	0.119	0.200	0.348
Thermal power (%)	-18.330	-17.150	12.781	11.790	-1.740	-1.363	-3.796	-3.488	232.037	197.552	2.908	2.646	8.014	13.730
Clean energy (%)	0	0	0	0	0	0	-63.202	-59.369	27.003	25.268	0.901	0.832	1.029	1.387

7.7 Discussion

7.7.1 Comparisons with other studies for China

As reviewed in section 6.2, several studies have already simulated the effects of a carbon tax in China. In this section, the results from this research will be compared with findings obtained by other CGE studies for China, such as the studies by Zhang (1996), Zheng & Fan (1999), Wang et al. (2009b) and Lu et al. (2009).

After an imposition of a carbon tax, the percentage changes in CO_2 emissions and GDP in this research are smaller[26] than those reported in Zhang (1996), Zheng & Fan (1999) and Wang et al. (2009b) but larger than those in Lu et al. (2009). For example, a carbon tax rate of RMB¥100/tC could reduce CO_2 emissions by 10.981% and decrease GDP by 0.613% in this research, but could only achieve 6.15% CO_2 reductions while leading to 0.38% GDP loss according to Lu et al. (2009). This may be due to the CGE models themselves. The models use different types of functions, choose different parameters and simulate under different assumptions, and so obtain different results. These differences could be considered as the distinguishing features of each research. However, another finding in this research, the decreasing marginal effect of carbon taxation, is consistent with the findings in Zhang (1996), Zheng & Fan (1999) and Lu et al. (2009).

The findings in relation to the sectoral effects of carbon tax on production, household consumption, imports and exports in this research are generally consistent with other literature. However, due to the different ways of dividing sectors in the models, the high-carbon content sectors in each research may be slightly different. For instance, this research finds that production of coal, natural gas and thermal power are affected most severely by a tax. Zheng & Fan (1999) argue that the oil, coking and electricity sectors had higher carbon intensity and would be negatively affected more by a carbon tax. Lu et al. (2009) show that the changes of household consumption, imports and exports in the oil sector are the largest, while their changes in the agriculture sector are the smallest among all the sectors.

[26] Less CO_2 emissions could be reduced at the same amount of carbon tax rate.

Most of the studies did not clearly explore the effects of a carbon tax on changing the energy consumption structure. Zhang (1996) finds that labour is released from the high-carbon content sectors due to output reduction effects, perhaps to be absorbed by the services sector, which is a low-carbon sector. In this research, however, it is found that labour flows from low-carbon to high-carbon content sectors because of the substitution effects between the input factors. The different results may be caused by different nesting structures of the production in the CGE models, namely, the substitution elasticities between input factors might be set differently. In the research of Zhang (1996), capital and labour are composited by a Cobb-Douglas function[27] to form a value-added aggregate. Coal, oil, natural gas and electricity also are combined by a Cobb-Douglas function to form an energy aggregate. Then, these two aggregates combine, by means of a CES aggregation function, to the composite input factors. However, the input factors in this research are composited one-by-one by CES functions (see section 6.3.1).

It is difficult to make comparisons with previous studies on the effects of recycling the carbon tax as the recycling methods used are different across the research. However, most findings (including this one) confirm the existence of cushion effects of complementary policy in China from different aspects. In this research, at a carbon tax rate of RMB¥100/tC, the GDP decreases by 0.613% and 0.556% under the independent carbon tax scenario and the carbon tax recycling scenario respectively. These results show that carbon tax recycling policy could help to cushion the negative impact of a tax on the economy in China, but this cushion effect is relatively limited, indicating that the possibility of 'double dividend' in China might also be relatively small. This finding is similar to that of other research. Lu et al. (2009) show that the negative impact of the carbon tax on production and competitiveness could be reduced little by reducing the enterprise tax at the same time, and household consumption could be simulated by subsidizing households. At a carbon tax rate of RMB¥200/tC, the decline of 0.74% GDP becomes 0.71% by reducing the enterprise tax and 0.67% by subsidizing households.

[27] In the Cobb-Douglas function, the substitution elasticity between the input factors is equal to one.

7.7.2 The suitability of using a carbon tax in China

The experience of the Taiyuan SO_2 emissions trading program so far does not provide much evidence in support of a carbon emissions trading scheme in China. The lesson from the Taiyuan case study is that the failure of the SO_2 emission trading program is because of the problems of design, information, regulation and market. It appears that there is no easy solution to these problems in the short term. Perhaps in the long term a Chinese carbon emissions trading scheme could be designed properly. But at this stage, China, as a developing country, does not have the information symmetry and free markets to make an ETS work. In addition, due to the weak legal basis and the bureaucratic environment, China would not be able to operate an effective ETS. Moreover, China has little experience in implementing an effective national carbon emissions trading scheme. Running an efficient emissions trading system requires a long-term learning and adaption process, which suggests that it may be not possible for China to use a carbon emissions trading policy to reduce carbon emissions in the short term.

However, China is under increasing pressure from the international community to make greater efforts to mitigate its carbon emissions. Researchers agree that GHG problems could not be solved without the participation of the large developing countries, especially China, India and Brazil (CPA Australia 2009). It is therefore necessary for China to take action and to participate in international efforts to reduce CO_2 emissions. While a carbon emissions trading scheme is not feasible in China in the short term, the alternative and effective policy a carbon tax should be considered. The results of the Chinese carbon tax CGE model in this study confirm that a carbon tax can reduce CO_2 emissions significantly with a relatively small negative impact on GDP. A carbon tax could be implemented and monitored relatively easily by using the current tax system (Ekins & Barker 2002). In fact, the EU plans to include all flights originating or landing in Europe into the EU ETS, which is actually a ‘carbon tariff’ (The Space Mart 2011). In addition, Australia has chosen a carbon tax as a transitional tool to control CO_2 emissions, with a commitment to establish a more efficient emissions trading system in the long term.

Australia planned for a carbon trading scheme in 2007. In 2008 the Rudd Government proposed the CPRS, as a cap-and-trade emissions trading system for

GHG_S and which was intended to take effect in July 2010 (Commonwealth of Australia 2008). However, the CPRS is argued to be flawed and poorly designed with too many exemptions and not enough incentives (ABC News 2009). Due to these criticisms and its potential negative impact on key economic sectors, the CPRS was rejected in the Australia Senate. The Productivity Commission of Australia advised that a carbon tax could be used as a transitional tool in mitigating GHG emissions because it is simple in administration and could be introduced in a revenue neutral way (The AGE 2007).

Considering the context and the emissions trading practice in China, it seems that a carbon tax is more suitable than carbon emissions trading for China at this stage. The experience of Australia suggests that China could also use a carbon tax as a transitional policy and move to a carbon emissions trading scheme when the market mechanism in China gets more mature. It has been reported that China will tax the most energy intensive industries and give preferential tax treatment to develop green technologies (Radio Australia 2011). In the meantime, China plans to implement an ETS by 2015, starting with a small pilot scheme in 2012. The findings of this research provide further evidence for the feasibility of these planned actions.

7.7.3 Policy implications for implementing a carbon tax in China

If a carbon tax policy was going to be adopted in China for reducing carbon emissions, the first question that needs to be answered is, 'At what level should the carbon tax be set?'. As a developing country, China still puts economic growth as its top priority, so it is unlikely that China would impose a high carbon tax. Moreover, starting with a relatively high carbon tax rate could make a carbon tax policy difficult to be accepted by industries and consumers alike. Therefore, in order to secure economic growth and to improve political feasibility, it might be better for China to start a carbon tax at a low level, and increase it gradually over time. Based on the findings from the Chinese carbon tax CGE model, it is suggest that RMB¥100/tC would be a suitable level initially. Under a carbon tax of RMB¥100/tC CO_2 emissions would decrease by 10.981% and GDP fall by only 0.613%, indicating that the reduction of CO_2 emissions would be relatively large while the negative impact on GDP would be comparatively small and acceptable. In addition, a carbon tax rate of RMB¥100/tC would be comparable with the charges in some other countries. For example, the recent price of certified emission reductions in the CDM market is around €13 (RMB¥104) (Point Carbon 2011). Australia's current carbon tax is AU$23/tC (RMB¥156/tC) .

It has been found that a carbon tax would affect the international competiveness of domestic industries in China, especially for carbon-intensive industries such as coal and natural gas. Thus it is suggested that a carbon tariff can be employed as a complementary policy to help domestic industries gain competitiveness in the international market. The carbon tariff includes rebating a carbon tax levied on the exported products directly or indirectly and imposing a similar level of carbon tax on imported products that have not been levied in the exporting country. Through the adjustments of this kind of carbon tariff, China could achieve its purpose of reducing carbon emissions by taxing the domestic energy industries while maintaining its international competitiveness by allowing exports to compete in untaxed markets and by taxing imports up to the same carbon tax level.

In addition to the international competitiveness, carbon-intensive sectors might be affected by a tax most seriously in term of productions. In order to protect carbon-intensive sectors, some literature suggests exempting them. However, Barker et al. (1993) argue that exemptions, which implies different tax rates between the exempted and un-exempted sectors, may lead to two problems. First, the demands of these exempted sectors will increase, which is a counteraction of a carbon tax. Second, the un-exempted sectors may try to be reclassified as exempt, and thus limit the impact of a carbon tax on energy consumption and CO_2 emissions. An empirical study for Norway confirms that extensive tax exemptions largely lower the effectiveness of the carbon tax in reducing CO_2 emissions (Bruvoll & Larsen 2004). Liang et al. (2007) compares two complementary policies – relieving all the sectors with a uniform tax rate and totally exempting energy- and trade-intensive sectors from a carbon tax. They find that an exemption policy would cause larger negative impacts and distortions. Therefore, including an exemption policy in a Chinese carbon tax scheme is not suggested. However, a subsidy for carbon-intensive sectors to use more clean energy or adopt cleaner technology could be useful. As the final aim of a carbon tax is to change the energy structure of the economy, subsidizing carbon-intensive sectors for using clean energy or clean technology could help to achieve this goal.

This research also shows that subsiding households as part of a carbon tax policy could help to simulate consumption and to alleviate the negative impacts of the tax on the economy. In addition, reducing indirect taxation of enterprises is argued by some researchers as a means to reduce the adverse impact of the tax on production and competitiveness (Liang et al. 2007; Lu et al. 2010). Therefore, when designing a carbon tax scheme for China, it would be better to use some complementary policies such as subsidizing households or reducing indirect taxation on enterprises, to relieve the negative impact of the carbon tax on the economy.

7.8 Conclusion

By using a CGE model, the impact of a carbon tax policy in China were simulated for the environmental effect, macroeconomic impact, sectoral effects and energy consumption structure effects. Two policy scenarios were considered: the independent carbon tax scenario and the carbon tax recycling scenario. In the independent carbon tax scenario, the results of six different carbon tax rates from RMB¥50/tC to RMB¥300/tC were compared. In the carbon tax recycling scenario, the case where all the carbon tax revenue is redistributed to households at the carbon tax rates of RMB¥100/tC and RMB¥200/tC respectively was considered. The main findings can be summarized as follows.

Overall the introduction of a carbon tax will have a negative impact on the economy. It will lead to decreases in household consumption, total consumption, exports, total demand and total supply, but cause an increase in imports.

It appears that a carbon tax is an effective policy for China as it can significantly decrease carbon emissions without dramatically impeding economy growth. For example, with a carbon tax of RMB¥100/tC the CO_2 emissions will decrease by 10.981%, while the GDP falls by only 0.613%. Moreover, the marginal effect of a carbon tax in reducing carbon emissions diminishes and the economy tends to contract at a decreasing rate as the carbon tax rate becomes higher. This is because with the carbon tax infinite high, the consumption of fossil energy could not be zero.

The sectoral effects of the carbon tax vary across the different sectors. The carbon-intensive sectors will be affected more severely in terms of production, imports and exports. There is no doubt that the coal sector would suffer most seriously from a carbon tax. Meanwhile, the energy structure will be improved after a carbon tax is imposed, with a shift from high-carbon factors to low-carbon or non-carbon factors.

Subsidizing households in the meantime could help to reduce the adverse effects of a carbon tax on the economy. Household consumption will increase from the baseline, thereby mitigating the reductions in GDP, exports, total demand and total supply. However, the magnitude of these reductions is relatively small, which implies that the cushion effect of subsidizing households in China is minimal and limited. In addition, the effects of a carbon tax on reducing carbon emissions and improving the energy consumption structure would be weakened by a lump-sum transfer to households.

Finally, this chapter compared the findings in this research with results from other studies for China and discussed the suitability of using a carbon tax in China. Considering the context and the emissions trading practice in China, it is suggested that a carbon tax is more suitable than a carbon emissions trading scheme at this stage. The experience of Australia with the carbon tax issue suggests that China could also use a carbon tax as a transitional policy and move to a carbon emissions trading system when the market mechanism becomes mature.

Chapter 8 Conclusion and policy implications

8.1 Summary and conclusion

Climate change has become a top concern worldwide. Scientific evidence has clearly indicated that the impacts of climate change are wide and serious. In order to tackle the threat of global climate change, the Annex I countries committed in the Kyoto Protocol to reduce carbon emissions by 5.2% below the 1990 level during the period 2008–12, while no developing countries, such as China, made such a commitment. Driven by urbanization and industrialization, carbon emissions in China increased rapidly in the last two decades: in 2006 China became the world's largest CO_2 emitter. Thus China is under great pressure to set a good example in mitigating carbon emissions. At the Copenhagen Summit in 2009, China made a voluntary commitment to reduce carbon emissions per GDP by 40–45% below its 2005 level by 2020. However, China currently mainly relies on command-and-control regulations to control carbon emissions, which may not be effective enough to achieve the target. There is an increasing concern about which policy instrument should be introduced for China to mitigate carbon emissions. This research attempted to find a suitable policy solution for China to reduce its carbon emissions and achieve its carbon reduction target in 2020. A summary of the discussions, findings and conclusions in each chapter follow.

Chapter 2 reviewed the four major policy options for reducing emissions: command-and-control regulations, subsidies, carbon tax and emissions trading. Each type of policy was reviewed, including relevant theories, practices and empirical studies. In particular, the emissions trading market, the key elements of a well-designed emissions trading program and the links from early schemes to national carbon trading schemes were discussed. By comparing these four kinds of policy options, it was concluded that command-and-control regulations are likely to be far less cost effective than other economic instruments in reducing emissions and they have many negative economic impacts on some sensitive sectors, and therefore this is not an optimal policy for reducing carbon emissions. Subsidies go against the polluter pays principle and are uncertain on the emission levels, and thus cannot be used as the central policy for mitigating carbon emissions. A carbon tax may be an acceptable policy option if the tax revenue is used to subsidize households or to offset other distortional taxes. It appears that emissions trading is potentially the most effective and efficient policy as it is theoretically more cost effective, more certain about emission levels and more easily linked to other countries' carbon reduction programs than the other options.

Chapter 3 is an institutional chapter. It first looked at the energy consumption, carbon emissions and climate change situations in China. Energy consumption and carbon emissions in China have increased rapidly in the past decades and would continue to increase strongly in the future. Climate change has caused adverse effects in China and the adverse impacts would be further increased by future climate change. Reviewing the existing climate change policies in China found that the existing policies and measures in China were not enough to combat the increasing carbon emissions and it is necessary for China to adopt a major and more effective national policy, such as a carbon tax or an ETS, to address the climate change problem. Referring to the conclusions reached in Chapter 2, carbon emissions trading was considered first. Research Q1 was proposed: *Is emissions trading a suitable policy for achieving carbon reductions in China?* Therefore, the emissions trading practice in China, particularly the SO_2 emissions trading program in Taiyuan city was reviewed. It appeared that no empirical studies had explored the recent outcomes of SO_2 emissions trading practice in China, and whether the outcomes were consistent with the theory or were the same as the initial expectation remained unknown. Chapter 3 then reviewed the carbon policy environment in China and the necessary conditions for using a carbon emissions trading policy in China, such as whether the emissions measurement, the Chinese market and the legal authority is accurate, free and adequate enough for supporting a cap-and-trade emissions trading program.

Chapter 4 presented the methodologies used for addressing research Q1 (Is *emissions trading a suitable policy for achieving carbon reductions in China?*), which were a case study and a GHG_S perspective interview. Following an explanation of the research framework, the Taiyuan SO_2 emissions trading case study was justified and described. As the only air pollutant emissions trading practices in China, the SO_2 emissions trading programs were the most available data than could be used for evaluating the introduction of a carbon emissions trading system in China. Being the most representative case, the Taiyuan SO_2 emissions trading program was chosen to reveal the actual emissions trading practice in China. Administrators from the Taiyuan EPB and managers in charge of SO_2 trading affairs from the participating enterprises were selected as the interviewees. Content analysis was used to analyse the interview data. Another GHG_S perspective interview was designed to collect experts' views on the implementation of a carbon emissions trading system in China. With the findings from the case study and the interviews, the question of whether emissions trading is a suitable policy for achieving carbon reductions could be addressed. Reliability and validity tests were reviewed to ensure that the qualitative research in this thesis was robust.

Contrary to expectation, it was found in Chapter 5 that the Taiyuan SO_2 emissions trading program was not functioning anything like the ideal emissions trading model. Though emissions were effectively reduced, innovation and investment in clean technology were promoted and no investment leakage was found after the program was introduced, participants' motivation was merely to comply with the caps rather than through the trading, implying that a similar result could be achieved with regulations. Moreover, whether cost savings had been realized or not was not clear. In addition, the Taiyuan SO_2 emissions trading program was found to be defective in design and weak in administration. The most serious problem was that a true SO_2 emissions trading market had not been formed yet. It appeared that emissions trading might not be suitable for China to achieve the carbon reduction target at this stage. The GHG_S perspective interview with experts on emissions trading and with policymakers on carbon problems further showed that the prerequisites of carrying out carbon emissions trading in China were not mature enough, leading to the conclusion that a carbon tax might be more appropriate currently. The research Q3 was thus proposed: *Is carbon tax a suitable policy for achieving carbon reductions in China?*

Chapter 6 described the Chinese carbon tax CGE model and the data used to assess the impact of introducing a carbon tax in China, the results of which could answer research Q3. CGE models were argued to be the most appropriate approach for environmental policy analysis: they had been applied to simulate the economic effects of a carbon tax in many countries, including China. It was assumed that the carbon tax in China was an excise tax and only applied to the production of three kinds of fossil energy – coal, oil and natural gas. The impact to be assessed not only includes the effectiveness of a carbon tax in reducing carbon emissions and the subsequent impact on China's economic growth, sectoral production and competitiveness, but also the effects on the energy consumption structure as this has not been examined in other studies. It should be noted that the Chinese carbon tax CGE model in this research was a static, multi-sectoral, open economy model that covered eleven sectors and was made up of eight modules. The SAM of China in 2007 was constructed as the data source for the CGE model on the basis of the 'Input-Output Table of China in 2007' and the *China Statistical Yearbook 2008*. A calibration approach was adopted to estimate some of the model parameters and the widely distributed non-linear programming package GAMS was used to solve the model.

In Chapter 7 the impact of a carbon tax in China were simulated in two different scenarios (an independent carbon tax scenario and a carbon tax recycling scenario) under different carbon tax rates, including the environmental, macroeconomic, sectoral and energy consumption structure effects. The results show that although the introduction of a carbon tax would have a negative impact on the economy, it appeared to be an effective policy as it could significantly reduce carbon emissions without dramatically impeding economic growth. The sectoral effects of the carbon tax differed among the sectors: carbon-intensive sectors would suffer the most. Interestingly, the model shows a shift away from high-carbon factors toward low-carbon or non-carbon factors, indicating that the energy structure would improve after a carbon tax was imposed.

However, the marginal effect of a carbon tax in reducing emissions, impeding economic growth, widening the gaps between sectors and improving energy consumption structure diminished as the carbon tax rate increased. By redistributing all the tax revenue to households, it was found that the adverse effects of the tax on the economy could be reduced to some extent, but the effect of the carbon tax in reducing carbon emissions and improving the energy consumption structure would be weakened. Considering the findings of emissions trading in China in Chapter 5 and the simulation results of the Chinese carbon tax CGE model in this chapter, it was suggested that a carbon tax might be more suitable than a carbon emissions trading scheme at this stage.

8.2 Policy implications of this research

This research aimed to find out what policy option China should adopt to achieve carbon reductions. Though emissions trading is argued to be the most effective and suitable policy for addressing climate change problem theoretically, it was found from the Taiyuan SO_2 emissions trading practice and the GHG_S perspective interviews that emissions trading might not be suitable for mitigating carbon emissions in China at this stage. This is because the institutional framework needed to support a cap-and-trade emissions trading program (e.g., an accurate and consistent emissions monitoring system, a consistent and objective enforceable measures, and an efficient free market) are not ready yet. Building these supporting infrastructures and using emissions trading in China will require considerable time, resources and effort. Considering that China does not yet have the institutional capacity in place to support a broad regional emissions trading program, it is preferable to develop a carbon tax at this stage. The results of the Chinese carbon tax CGE model in this research confirmed that the tax could be an effective policy in reducing carbon emissions significantly with a relatively small negative impact on economic growth. The experience of Australia with a carbon tax suggests that China could also use a carbon tax as an initial tool to control carbon emissions and move to a carbon emissions trading system in the long run when the market mechanism becomes mature and the institutional capacities are in place.

8.3 Main contributions of this research

This thesis has made five significant contributions to the body of knowledge as well as the practice of addressing climate change.

First, this thesis provides a comprehensive review of the theoretical and empirical literature on the four main policy options used to reduce carbon emissions. It has detailed China’s energy consumption, carbon emissions, climate change situations and existing climate change policies, which provides a comprehensive understanding of the Chinese carbon context.

Second, this is the first research that explores the SO_2 emissions trading practice in China from first-hand data. The findings of the Taiyuan SO_2 emissions trading program in this research not only enriches emissions trading literature for China, but also provides policy suggestions on carbon reduction options and helps to improve the administration of the current program. In addition, the experience of the Taiyuan SO_2 emissions trading program in this research can contribute to a better design and implementation of other emissions trading programs as well as a future carbon trading program in China.

Third, the carbon tax CGE model of the Chinese economy and environment used in this research has improved existing models in three aspects. First, the electricity sector is divided into thermal power and clean energy sectors according to the means of generating electricity, and attempted to simulate the impact of a carbon tax on optimizing the energy structure more precisely. Second, the energy mix production function employs a CES function instead of the Cobb-Douglas function, which allows for the substitution elasticity between energy factors not being equal to one. Third, the energy factors are nested individually, which overcomes the limitation that every two energy factors have the same substitution elasticity and facilitates an investigation of the changes of energy consumption structure. In addition, the effects of the carbon tax on improving energy consumption structures have been first investigated by using the CGE model, which fills a research gap for China.

Fourth, this research provides rigorous evidence for policymakers to make related policy decisions. For example, the carbon tax simulation results from the proposed Chinese carbon tax CGE model can be very useful for policymakers to comprehend the carbon tax at the national level.

Finally, this research may motivate other developing countries to actively participate in finding a suitable policy solution for mitigating their national carbon emissions.

8.4 Limitations and future research

While this thesis has achieved its main objectives, there are still some limitations, mainly owing to the methodologies used and the unavailability of data. Future research should try to overcome the limitations.

First, it was not possible to include all the SO_2 emissions trading practices in China in the case study analysis. For example, only a little second-hand information for the SO_2 emissions trading program in Henan province could be found. Also, because of the inability to investigate two or more SO_2 emissions trading practices personally, the case study in this research is a single case and the readers should be cautious in generalising the findings from the Taiyuan case.

Second, CGE models have some inherent limitations for practical policy decisions. The most frequently mentioned limitation is the lack of empirical validation[28] (Borges 1986). Furthermore, they are built on the general equilibrium assumption and the perfect competition assumption, which might not be representative of the real world. These limitations are common to almost all modelling simulations.

Third, the Chinese carbon tax CGE model in this research is not a dynamic CGE model. This is partly due to the unavailability of data for a dynamic CGE model. Also, a static CGE model is believed to be sufficient for achieving the research purpose. But limitation of the static CGE model is that it does not account for the possible technology progress that enables firms to more efficiently utilize the energy inputs, which in turns help to reduce the emissions. Future research could construct a dynamic Chinese CGE model that considering the price-induced technological change to predict the impact of a carbon tax in the long term.

Fourth, the lump-sum transfer of the tax revenue in the CGE model is equal to every household without any regard to the income level of the households. Future research would be possible to disaggregate the households into several deciles so that compensation can be carried out favouring the low income households as generally discussed in the literature.

Fifth, the clean energy data used in the Chinese carbon tax CGE model are estimated data. In the 42-sectors I/O table, the clean energy sector is part of the electricity sector. It is separated from the electricity sector by using the Electricity Balance Table in the *China Statistical Yearbook 2008*. However, the input and output data of clean energy in different sectors could not be found and can only be estimated on the

[28] Most of the CGE models are calibrated rather than econometrically estimated. The calibration procedure is based on the elasticities borrowed from other literature, which may be not suitable in the research due to different definitions of variables or level of disaggregation (Zhang 1996).

basis of the average percentage of used and produced clean energy. Future research could use the actual clean energy data and generate more precise simulation results.

Sixth, the econometric approach was not applied in estimating the relative parameters of the CGE model due to insufficient time-series data and computing resources. Future research could use the econometric approach instead of the calibration approach to estimate some of the parameters of the CGE model.

Finally, future research could use a CGE model to examine the existence of 'double dividend' in China (i.e. levy a carbon tax while cut other distorting taxes such as the income tax), or include both a carbon tax and an ETS in one CGE model to obtain some more exciting results.

8.5 A final word

When I had all but finished this thesis, *Economic Information Daily*, a state-run Chinese newspaper reported that proposals for a new environmental taxation system had been submitted for review to the Ministry of Finance (Liang & Wang 2012; Maher & Sainsbury 2012). In the proposal, a carbon tax scheme, aimed primarily at large users of coal, crude oil and natural gas, is expected to be implemented before the end of China's 2011–15 five year plan. The tax rate is likely to be RMB¥10 (US$1.59) for each tonne of carbon but will increase gradually. In addition, it is said that the Chinese Government has been working on plans to pilot emission trading schemes in key provinces and cities from 2012, with a national program to be operating by 2015 (Maher & Sainsbury 2012; Radio Australia 2011). A spokesman for Australian Climate Change Minister Greg Combet said China was already taking action to tackle climate change.

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Appendix 1 List of important events in emissions trading practices in China

Time	Events and Activities
1987	China started an emission permits pilot in water pollution.
	Emissions permits were transferred between the Shanghai 10th Steel Factory and the Tangshan Electroplating Factory in Minhang District, Shanghai. The Electroplating Factory was compensated RMB¥40 000 for the economic loss every year.
	Shanghai Novel Colour Picture Tube Co. Ltd. bought emission permits of 395 kg CO_2 per day from Shanghai Hong Wen Mills.
1987–present	Since the water pollutants emissions trading was carried out in Minhang District, Shanghai, 37 transactions have been achieved, involving 1301 kg/d CO_2 emissions permits and RMB¥13.91 in total.
March 1988	‘Interim measures on the management of water pollutants emissions permits’ was released by SEPA.
June 1988	SEPA identified 18 cities as pilot units for implementing water pollutants emissions permits, including Shanghai, Beijing, Tianjin, Shenyang, Xuzhou and Changzhou.
July 1989	According to the Article 9 of ‘Water Pollution Control Act implementation rules’, the enterprises or institutions that discharge pollutants into the water should be regulated by the emissions permits.
1990	SEPA began selecting some cities for piloting air pollutants emission permits, including Baotou, Liuzhou, Taiyuan, Pingdingshan, and Yangzhou.
April 1991	SEPA began the air pollutants emissions permits pilot in 16 cities.
1993	Kaiyuan City Government, Yunnan Province published the ‘Interim measures on the management of air pollutants emission permits in Kaiyuan’. The Kaiyuan EPB released the ‘Measures on air pollutants emissions trading in Kaiyuan’, indicating the implementation of total quantity charges and emissions trading for SO_2, smoke and dust.
	Local laws and regulations in Liaoning Province stipulated that all pollutant emissions units must be managed by permits.
1994	SEPA carried out air pollutants emissions trading in Baotou, Kaiyuan, Liuzhou, Taiyuan, Pingdingshan and Guiyang cities.
	SEPA announced the end of emission permits pilot work and started to implement the emissions permits system in all of the pilot cities.
1995	According to the Article 19 of ‘Water Pollution Control Ordinance in Huaihe River Basin’, all emission permit owners in the Haihe River Basin should ensure that their emission amount is no more than the total emissions quantity stipulated by the emission permits.
September 1996	In ‘The plan of controlling the total emission quantity of the national major pollutants in the 9th Five-year Plan’, the State Council formally proposed total quantity control as one environmental policy, which provided the system basis for implementing emissions trading in China.
1997	The Beijing Environment and Development Committee and the US Environment Defense Fund (EDF) carried out a research project on emissions trading. In the first stage of the project, Benxi and Nantong were chosen as the case study cities for the research on implementing emissions trading at the city level.
	In Jiaxin the EPB, the Price Department and the Finance Department published ‘The measures on the management of total quantity control of water pollutant emissions and the compensation of using emissions right in Shuizhou District’. The Shuizhou Wastewater Treatment Co. Ltd, a state-owned asset management company, was responsible for collecting the fees for using emissions rights. All the fees were used for constructing the living wastewater treatment factories in the villages of the district.

August 1998	Taiyuan adopted the 'Administrative regulation for total quantity control of air pollutants emissions in Taiyuan city', which is the first local regulation that includes total quantity control of emissions trading in China.
April 1999	During the visit of Premier Zhu Rongji to the US, Mr Xie Zhenhua (the director of SEPA in China) and Ms Carlo Brown (the director of the US EPA) signed a cooperation agreement, which included a project named 'The feasibility research on using market mechanism to reduce SO_2 emissions in China'. Nantong, Jiangsu and Benxi, Liaoning were selected as the pilot cities for this project.
September 1999	SEPA and the EDF signed a memorandum of cooperation on 'The research on how to use the market instruments to help the local governments and enterprises achieve the total quantity control of pollutants emissions stipulated by the State Council'.
November 1999	SEPA and the EPA held 'The international seminar on discussing the feasibility of implementing SO_2 emissions trading in China' in the Beijing International Conference Centre.
March 2000	Article 10 of the revised 'Rules for the implementation of the Water Pollution Control Act': the local EPB allocates the water pollutant emission permits according to the total quantity control plan.
April 2000	Article 15 of the revised 'Air Pollution Control Act': implement total quantity control and emissions permits system for the major air pollutants in the regions not meeting the prescribed air quality standards and the two acid rain control areas designated by the State Council. This provides a legal basis for total quantity control policy.
October 2000	Fifteen experts from SEPA, the State Planning Commission, the Chinese Research Academy of Environmental Science, Benxi EPB and Nantong EPB visited the US and investigated the US SO_2 emissions trading program. They held 'The second seminar of using market mechanism to control SO_2 emissions in China and US' in the US with the EPA.
November 2001	Dongyang and Yiwu, two cities in Jinhua District, Zhejiang Province, signed an agreement for transferring water rights. The Yiwu city paid RMB¥0.2 billion to Dongyang for the permanent use right of 50 million m^3 water in Hengmian water reservoir. This is the first water rights trading between cities in China.
2001	SEPA, the State Electricity Company and the US EDF organized several seminars regarding SO_2 reductions and emissions trading in Huangshan, Beijing, Nanjing etc.
September 2001	The ADB and the Shanxi Provincial Government launched the 'SO_2 emissions trading program', which was implemented by the RFF and CAEP jointly. This program was piloted in Taiyuan city and 26 large enterprises participated.
	With the help from the RFF and CAEP, Taiyuan drafted the 'Administrative regulation for SO_2 emissions trading in Taiyuan city', which is the first local regulation on SO_2 emissions trading in China.
	Nantong Tiansheng Guangfa Power Co. sold 1800 t SO_2 emissions permits to Nantong Acetate Fiber Co. Ltd, with a contract lasting for 6 years.
2002	Jiangsu Taicang Port Green Power Co. Ltd bought annual 1700 t SO_2 emissions permits from 2003–05 from Nanjing Shimonoseki Plant.
	The Hongkong Special Administration Government and the Guangdong Provincial Government published 'Joint announcement of improving the air quality in Pearl River Delta': both areas are respectively responsible for 30% SO_2 reductions by 2010, and emissions trading is considered as one of the instruments for both areas to cooperate in reducing air pollutants emissions.
March 2002	SEPA published 'The notice of promoting the total quantity control and emissions trading research projects of SO_2', implementing SO_2 total quantity control and emissions trading demonstration work in the Shandong, Shanxi, Jiangsu, Henan, Shanghai, Tianjin, Liuzhou provinces or cities. The largest emissions trading demonstration work launched by the Chinese government so far.
May 2002	SEPA published 'The notice of organizing the SO_2 total quantity control and

	emissions trading demonstration work', and cooperated with the EDF in implementing pilot projects of 'SO_2 Total Quantity Control and Emissions Trading' in the Shandong, Shanxi, Jiangsu, Henan, Shanghai, Tianjin, Liuzhou provinces or cities.
June 2002	Xiuzhou District, Jiangxing city firstly carried out pilots in emissions trading. All the emission enterprises must buy the 'original' emissions permits first and then introduce the emissions permits into the market for trading.
July 2002	SEPA organized 'SO_2 emissions trading' pilot meeting with Shandong, Shanxi, Jiangsu, Henan, Shanghai, Tianjin, Liuzhou provinces or cities, clearly defining the specific steps and implementation plan of the emissions trading pilot work.
September 2002	'The 10th Five-year Plan of acid rain and SO_2 pollution control in two control areas', which was approved and conducted by the State Council, started to implement SO_2 total quantity control and emission permits in two control areas.
October 2002	The Taiyuan Government published the first city level regulation on SO_2 emissions trading: 'Administrative regulation for SO_2 emissions trading in Taiyuan city (trial)'.
	The Jiangsu EPB and the Jiangsu Economy and Trade Office jointly designed 'Interim measures on the management of SO_2 emissions trading in Jiangsu electric power industry'.
October 2002	Eleven enterprises from Honghe and Wangdian Villages, Xiuzhou District, which are famous for sweater dyeing, participated in the launch ceremony of the first compensation using emission rights. The trading contracts between the enterprises involved RMB¥1.4359 million.
2003	With coordination from the Henan EPB, Yima Coal and Gas Co. bought 900 t SO_2 emissions permits annually from the Henan Zhongyuan Gold Smelter.
	The State Electric Power Changzhou Generating Co. Ltd paid Zhenjiang Jianbi Power Plant RMB¥3 million annually for 2000 t SO_2 emission permits per year for 2006–10.
March 2002	In the Tenth National People's Congress Meeting, Xie Zhenhua, the director of SEPA, clearly expressed that China started to pilot SO_2 emissions trading in some key areas.
April 2002	SEPA and the EDF cooperated in carrying out training seminars on SO_2 total quantity control and emissions trading nationally.
December 2005	The 'Implementing the scientific concept of development and strengthening environmental protection' suggested implementing total quantity control for the pollutants, promoting emissions permits system and carrying out pilots in emission trading.

Data source: Adopted from Wang et al. (2009a, pp. 34-6)

Appendix 2 Progress on emissions trading practice since 2006

Date	Activities	Policy Scope	Policy Objects
March–June 2006	The Ministry of Finance and the former SEPA jointly investigated emission trading schemes and compensation for the use of emission rights.	Nationwide	Air and water pollutants emissions trading
30 August 2006	The City University of Hong Kong organized a seminar, 'Emissions trading in China: from concept to practice'.	Electric Power Sector in Hong Kong	SO_2, NO_X etc.
January 2007	The Minister of Finance suggested steadily promoting pilot projects in reforming the compensation for the use of resources and environment.	National Power Sector and Taihu Lake Basin	SO_2, COD, Ammonia
30 January 2007	Guangdong and Hong Kong Governments published 'The experimental plan of implementing emissions trading in thermal power plants in the Pearl River Delta'.	Region (Pearl River Delta)	Mainly SO_2, also included NO_X , and PM_{10}
March 2007	'The technology research for SO_2 emissions trading in electric power sector' was started with the support of national technology.	National Electric Power Sector	SO_2
29 April 2007	The first SO_2 emissions trading scheme implemented in Wuhan, Hubei Province.	Region (Wuhan city)	SO_2
1 July 2007	The Ministry of Finance and SEPA decided to carry out emission trading pilot projects in the electric power sector and Taihu Lake Basin.		SO_2, COD, Ammonia
7 June 2007	The 'Comprehensive proposal on energy conservation' from the State Council proposed the finishing of the drafting of the administrative regulations on the management of SO_2 emissions trading and so on.	National Electric Power Sector	SO_2
13 August 2007	Zhuji city published 'Interim regulations on the compensation for the use of pollutants emission permits in Zhuji city'.	District (Zhuji city)	SO_2, COD
29 August 2007	Zhuji city published 'Rules for the implementation of the interim regulations on the compensation for the use of pollutants emission permits in Zhuji city'.	District (Zhuji city)	
September 2007	The 'Rules on water pollution control in Taihu Lake (revised)' was approved by the Standing Committee of the Jiangsu People's Congress. It suggested that the Taihu Lake would gradually carry out the paid initial allocation and trading of major water pollutants emission permits.	Region (Taihu Lake, Jiangsu)	COD
27 September 2007	The Jiaxing Government published 'Rules on the implementation of emissions trading of the major pollutants in Jiaxin city (Trial)'.	District (Jiaxin city)	COD, SO_2
10 November 2007	Jiaxing established the first domestic emissions trading institution – Emission Allowances Reserve and Trade Centre.		COD, SO_2
13 December 2007	The Ministry of Finance and SEPA approved Jiangsu carrying out pilot projects in the paid use and trading of emission rights in Taihu Lake.	`	Mainly CO_2

31 December 2007	Jiangsu, Zhejiang and Shanghai planned to carry out joint pilot projects in the paid use and trading of emission rights in the Yangtze River Delta region.	Region (Yangtze River Delta)	COD, SO_2
31 December 2007	The third China-US strategic dialogue established cooperation in the SO_2 emissions trading of electric power sector.	Nationwide	SO_2
1 January 2008	The ‘Administrative regulations on the charges of using the major water pollutants emission rights in Taihu Lake, Jiangsu (Trial)’ was implemented.	Taihu Lake Basin, Jiangsu	COD, Ammonia, Total Phosphorus
1 January 2008	The ‘Administrative regulations on the charges of using the SO_2 emission rights in Jiangsu (Trial)’ was implemented.	Jiangsu Province	SO_2
March 2008	Wuhan Guanggu Property Exchange planned to establish a platform for emissions trading, bringing emissions trading into the property trading market.	Region (Hubei Province)	COD, SO_2
25 March 2008	The ‘Administrative regulation for SO_2 emissions trading in Taiyuan city’ was formally implemented.	District (Taiyuan city)	SO_2
May 2008	The Tinjin Property Rights Exchange, CNPC Assets Management Co. Ltd and the Chicago Climate Exchange prepared the establishment of the Tianjin Emissions Exchange.	Natiowide	Quantifiable, indicator and standardized environmental products
15 May 2008	The National Environmental Economics Institute and the Pilot Technology Team conducted emissions trading investigations in Jiangsu and Zhejiang.	Electric Power Sector and Taihu Lake	CO_2, SO_2
11 June 2008	The Environmental Planning Institute of SEPA began to develop the management platform for the SO_2 emissions trading in the electric power sector.	Electric Power Sector	SO_2
17–18 June 2008	A seminar, ‘Paid use and trade of water pollutants emissions rights’, held by the Environmental Planning Institute of SEPA in Jiaxing.	Nationwide	Water pollutants emissions trading
5 August 2008	The Beijing Environment Exchange was established.	Nationwide	A trading platform for environmental products.
5 August 2008	The Shanghai Environment & Energy Exchange was established.	Nationwide	A trading platform for all kinds of interests in the environment and energy.
30 June 2008	The ‘Plan of piloting the paid use and trading of the major pollutants emission rights in Zhejiang Province’ was demonstrated by experts.	Region (Zhejiang Province)	COD, SO_2
6 August 2008	The ‘Overall plan of implementing comprehensive pilots of emissions trading in Binghai New District, Tianjin’	Nationwide	COD, SO_2 ,carbon emissions and so on
14 August 2008	The Ministry of Finance, SEPA and the Jiangsu Provincial Government launched pilot projects on the paid use and trading of major water pollutants emission rights in	Regions (Su, Xi, Chang along the Taihu Lake and	COD

	Taihu Lake in Wuxi city.	areas of Nanjing, Zhenjiang)	
10 September 2008	Heilongjiang SO_2 emissions trading platform was established.	Heilongjiang Province	SO_2
24 September 2008	The Tianjin Emissions Exchange was established, auctioning the excess allowances.	International (CO_2) Domestic (COD, SO_2 etc.)	COD, SO_2 ,carbon emissions, environmental technology, energy services etc.
November 2008	An international seminar of emissions trading was held by the Environmental Planning Institute of SEPA in Nanjing.		

Data source: Wang et al. (2009a, pp. 37-8)

Appendix 3 Administrative regulations for SO2 emissions trading in Taiyuan city

1. In order to protect and improve the environmental air quality, achieve the total quantity control target of sulphur dioxide at the least cost through sulphur dioxide emissions trading, and promote the harmonious development of environment, society and economics, this regulation is established according to 'The People's Republic of China Air Pollution Prevention Law' and 'Administrative Regulation on the Total Quantity Control of Air Pollutant Emissions in Taiyuan city', and the actual situation in Taiyuan city.

2. The sulphur dioxide emissions trading is refer to: the activities of buying and selling the sulphur dioxide emission allowances between the pollution discharge units under the total quantity control.

3. All the sulphur dioxide emission units in the administrative division scope of Taiyuan city are covered by this regulation.

4. All the sulphur dioxide emissions trading should obey the rules of market economy, and the allowances in the total quantity control can be transferred with compensation under the instructions of the government.

5. The city environmental protection administrative department is responsible for the supervision and management of the sulphur dioxide emissions trading. The related Plan, Economy, Law, Finance and Price departments manage the sulphur dioxide emissions trading according to respective responsibility.

6. The units engaged in sulphur dioxide emissions trading are not exempted from other legal obligations of environmental protection.

7. According to the total national and provincial quantity control targets of sulphur dioxide emissions, the city environmental protection administrative department formulates the total quantity control objective and the yearly reducing plan of sulphur dioxide emissions for this city.

8. Based on the total quantity control target and the data reported by the pollution discharge units and then approved by the city environmental protection administrative department, the city environmental protection administrative department works out five-year's sulphur dioxide emissions yearly emission allowances in the first year of each five-year's plan. The emissions allowances are allocated to the pollution discharge units after authorizing by the people's government of the city.

9. In the yearly emission allowances received by each pollution discharge unit from the city environmental protection administrative department, each ton of sulphur dioxide allowable emission is equal to a sulphur dioxide emission allowance.

10. The reduced sulphur dioxide emission allowances, which due to the central supply of heat, closing down, suspension of business, merging, transferring, moving and bankruptcy, should be recalled or adjusted in time by the city environmental protection administrative department.

11. The sulphur dioxide emission allowances of the existing pollution discharge units will not be increased because of the reconstruction, extension, merge and separation. The newly built enterprises can obtain the yearly emission allowances by trading, and participate in the sulphur dioxide emission allowances distribution in the next five-year plan.

12. The sulphur dioxide emission allowances owned by the pollution discharge units can be traded. The surplus emission allowances can be stored, but cannot be used in advance.

13. When use the storage allowances, the pollution discharge units must fill in 'Taiyuan application of using sulphur dioxide storage allowances'. The storage allowances only then can be used after being approved by the city environmental protection administrative department.

14. The allowances trading adopt the way which both parties have agreed. Based on the reducing cost of sulphur dioxide and the market conditions, the trading price is decided freely by the both parties. The buyers and sellers need to sign the 'Taiyuan sulphur dioxide allowance trading contract' after concluding a transaction. The contract only then becomes effective after being identified and filled by the city environmental protection administrative department.

15. The recalled or adjusted allowances, which are brought forth because of the above article 10 and so on, can be auctioned by the city environmental protection administrative department. The concrete details of auction are formulated by the city environmental protection administrative department.

16. The pollution discharge units can obtain the emission allowances by auctioning. The auction income is turned in the finance to improve the air quality specially.

17. For the pollution discharge units, the actual sulphur dioxide emissions in each year are no higher than the sulphur dioxide emission allowances that they hold at the end of the year.

18. The city environmental protection administrative department establishes the sulphur dioxide emission allowances tracking system and the transaction management system, sets up the sulphur dioxide emission account to track the target enforcement and allowances trading of each pollution discharge unit, and publishes the information and the guiding price of sulphur dioxide emission trading.

19. The pollution discharge units should install the continuously online monitoring equipment to accurately measure and master the emissions of sulphur dioxide, and then pass the data to the city environmental monitoring central station regularly.

20. Each pollution discharge unit must fill in 'Taiyuan pollution discharge units' seasonally report of sulphur dioxide' in the end of each season and 'Taiyuan pollution discharge units' yearly report of sulphur dioxide' before 15^{th} January of each year, and then report them to the city environmental protection administrative department for approving.

21. If the pollution discharge units want to change the emission way of sulphur dioxide, they should submit applications to the city environmental protection administrative department 30 days in advance, and fulfil the change registration

formalities. They cannot change the way if the applications are not approved. If the city environmental protection administrative department has not replied clearly in 20 days since the submission of the application, it is regarded as the agreement of the change.

22. In March of each year, after compiling ‘Taiyuan sulphur dioxide emissions yearly report’ and ‘Taiyuan sulphur dioxide emission allowances trading contract’ of all the pollution discharge units in the city, the city environmental protection administrative department publishes last year’s ‘Taiyuan sulphur dioxide emissions and emissions trading bulletin’, notifying the sulphur dioxide emission allowances and transactions information of pollution discharge units.

23. The pollution discharge units, whose actual sulphur dioxide emissions surpass the emission allowances they owned in the whole year, will be fined from 3000 to 8000RMB per excessive allowance by the city environmental protection administrative department, but the total penalty is less than 30000RMB.

24. Without the confirmation of the city environmental protection administrative department, the emissions trading is regarded as the invalid trading. And both the trading parties will be fined from 3000RMB to 30000RMB by the city environmental protection administrative department.

25. The units violate other relevant provisions of this regulation will be punished by the city environmental protection administrative department according to relevant laws and regulations.

26. The enforcement officers of environmental protection administrative department, who neglect of duty, abuse of power, play favouritism and commit irregularities during the implementation of the supervision and management of sulphur dioxide emissions trading, will be administrative executed by the unit or the higher authorities. Those constitute a crime shall be held criminal responsibility.

27. The pollution discharge units who are unsatisfied with the administrative penalty decision can apply for administrative reconsideration or bring an administrative lawsuit.

28. The specific issues in the application of this regulation are interpreted by the legislative affairs office of municipal government, and organized and implemented by the city environmental protection administrative department.

29. This regulations are put into force after 30 days of announcement.

Appendix 4 Interview questions 1

Interviewees: Managers response for the emissions trading affairs in the companies

General information:

1. How long have you been working in this company? ....
2. What is your position now? ....
3. How long have you been working in this position? ....

Interview questions:

Part 1: Basic situation of your company

1. Could you please give a brief introduction of your company at first?
   (1) Background or history
   (2) The main business and employees
   (3) The total assets, net profits, market share and production of your company
   (4) Fuel price, energy consumption and emission cost
   (5) How does the government support your business?
   (6) Where can I get more information about your company?
2. How is the SO_2 emissions trading going for your company?
   (1) How many emission permits were allocated to your company annually since 2003?
   (2) How many emissions did your company actually emit each year?
   (3) Have your company done any transactions of emission permits since the SO_2 trading program was implemented?
   (4) If so, how many times? When? With whom? How much? Why?
   (5) Where can I get more information on your emissions trading?

Part 2: The SO_2 trading practice

1. What are the impacts of SO_2 trading program on your company?
   (1) The emission amount
   (2) The emission cost
   (3) Innovation and investment in clean technology
   (4) Direct and indirect investment outside Taiyuan city
   (5) Any other impacts?
   (6) Where can I get more information?

2. What do you think about the SO_2 trading program?

(1) Is it effective in reducing the SO_2 emissions?

(2) Is it better than the previous command-and-control regulations?

3. As your known, what do other companies covered by the SO_2 trading program do in facing of the SO_2 cap-and-trade program?

4. In your opinion, what are the problems of the existing SO_2 trading program?

5. Could you please give some suggestions for making it better?

Part 3: The future carbon trading program

1. From your experience with SO_2 trading, what do you think about using emissions trading to achieve carbon reductions?

2. What kind of experiences or lessons you have learned from SO_2 trading practice that would be applicable for carbon trading?

3. Based on the SO_2 practice, how to design the key features of a carbon trading scheme if it were going to be implemented in China?

(1) Targets

(2) Coverage

(3) Allocation

(4) Banking and borrowing

(5) Linkage

(6) Monitoring and enforcement

(7) Any other features need to be considered carefully?

Appendix 5 Interview questions 2

Interviewees: Administrators from the Taiyuan Environmental Protection Bureau

General information:

1. How long have you been working in the Environmental Protection Bureau? ....

2. What is your position now? ....

3. How long have you been working in this position? ....

Interview questions:

Part 1: The SO_2 trading practice

1. How is the SO_2 trading program going since it was implemented?

    (1) Number of trades between companies

    (2) When? Who? Why? How much?

    (3) Enforcement, monitoring and leakage

    (4) Where can I get more information?

2. What are the impacts of SO_2 trading program on the companies?

    (1) The emission amount

    (2) The emission cost

    (3) Innovation and investment in clean technology

    (4) Direct and indirect investment outside Taiyuan city

    (5) Any other impacts?

3. What do you think about the SO_2 trading program?

    (1) Is it effective in controlling or reducing the SO_2 emissions?

    (2) Is the SO_2 trading market really existing?

    (3) Is it better than the previous command-and-control regulations?

4. What have the government done to help the 23 companies adopt the SO_2 cap-and-trade program?

    (1) Direct financial support

    (2) Indirect financial support

    (3) Other supports

    (4) Where can I get more information?

5. In your opinion, what are the major problems of the existing SO_2 trading program?

6. How could the SO_2 trading program be improved?

Part 2: The future carbon trading program

1. From your experience with SO_2 trading, what do you think about using emissions trading to achieve carbon reductions?

2. What kind of experiences or lessons you have learned from SO_2 trading practice that would be applicable for carbon trading?

(1) What might be the differences between SO_2 trading and carbon trading?

(2) Anything unusual about Taiyuan city compared to other regions?

3. Based on the SO_2 practice, how to design the key features of a carbon trading scheme if it were going to be implemented in China?

(1) Targets

(2) Coverage

(3) Allocation

(4) Banking and borrowing

(5) Linkage

(6) Monitoring and enforcement

(7) Any other features need to be considered carefully?

Appendix 6 Interview questions 3

Interviewees: policy-makers, scholars on carbon reductions issue and managers from Carbon Exchanges

General information:

1. What kind of work you are engaged in? ....

2. What is your position now? ....

3. How long have you been working in the carbon area? ....

Interview questions:

1. What do you think about using emissions trading to achieve carbon reductions?

2. What are the necessary considerations for China when using emissions trading to achieve carbon reductions?

   (1) Market conditions

   (2) Economic development level

   (3) Legal base and enforcement

   (4) Is China different to EU situation?

3. How to design the key features of a carbon trading scheme if it were going to be implemented in China?

   (1) Targets

   (2) Coverage

   (3) Allocation

   (4) Banking and borrowing

   (5) Linkage

   (6) Monitoring and enforcement

   (7) Any other features need to be considered carefully?

Appendix 7 Plain language statement

University of Southern Queensland

The University of Southern Queensland

Plain Language Statement

TO: Participants

Full Project Title: Emissions Trading in China: Lessons from Taiyuan city

Student Researcher: Zhen (Jane) Lu

I am Jane, a PhD candidate in Faculty of Business, University of Southern Queensland, Australia. My research project is about the emissions trading in China. I would like to invite you to take part in this research project.

You are invited to participate in this research project because (your company is included by the SO_2 trading program in Taiyuan City. As the manager responsible for SO_2 trading affairs in the company, you have the first hand information of the emissions trading practice. I got your private contact details from the official website of the company.)(you are the administrator from the Taiyuan Environmental Protection Bureau who in charge of the SO_2 trading program in Taiyuan City. As the representative of the administrators, you have the absolute qualification to talk about the lessons and experience of the emissions trading in China. I got your private contact details from the official website of Taiyuan Environmental Protection Bureau.) (you are an scholar expert on carbon reductions issue. I got your private contact details from your published journal articles.) (you are the manager of the Carbon Exchange who are an expert in carbon trading area. I got your private contact details from the official website of the Shanghai/Tianjin Carbon Exchange.) (you are the policymaker on the carbon reductions issue who has the administrative power to make policy decisions or at least has influence on policy decisions of carbon reductions issue. I got your private contact details from the official website.)

Please read this Plain Language Statement carefully. Its purpose is to explain to you as openly and clearly as possible all the procedures involved so that you can make a fully informed decision as to whether you are going to participate. Feel free to ask questions about any information in the document. You may also wish to discuss the project with a relative or friend or your local health worker. Feel free to do this.

Once you understand what the project is about and if you agree to take part in it, it is asked that you sign the Consent Form. By signing the Consent Form, you indicate that you understand the information and that you give your consent to participate in the research project.

1. <u>Purpose of Research</u>

The purpose of this project is to investigate whether emissions trading as a policy option can help China achieve carbon reductions. This research project will help the researcher obtain the PhD degree.

Previous experience has shown that emissions trading, as a market-based policy, may be the most suitable instrument for reducing carbon emissions. But at this stage, it is difficult to assert which policy instrument is more effective in reducing carbon emissions in China in the absence of large scale applications and rigorous analysis. If an emissions trading system were going to be implemented in China to reduce carbon emissions, its effectiveness and design features need to be carefully assessed by examining the evidence from existing emissions trading practice in China and elsewhere.

2. Procedures

Participation in this project will involve

- The interview will be a face-to-face semi-structured interview. Each participant will be interviewed for one time and each interview will last for 45-60 minutes.

- Tape recording will be considered during the interview. But if the interviewee feels uncomfortable about recording, the researcher will take notes instead.

- The participants will get both environmental and economic benefits for taking part in the research.

- No potential risks are expected for the participants.

3. Confidentiality

The digital data will be stored on a special disk with encryption. The written documents and recording tapes will be locked in a personal filing cabinet. According to the rules, all the data will be stored for 5 years and then destroyed.

Any information obtained in connection with this project and that can identify you will remain confidential. It will only be disclosed with your permission, subject to legal requirements. If you give me your permission by signing the Consent Form, I plan to publish the results in a PhD and academic journals.

In any publication, information will be provided in such a way that you cannot be identified. The conclusions of the study will be drawn in aggregate terms and any individual opinion will be reported in a de-identified form.

4. Voluntary Participation

Participation is entirely voluntary. **If you do not wish to take part you are not obliged to.** If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. Any information already obtained from you will be destroyed.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect your relationship with the University of Southern Queensland.

Before you make your decision, the researcher will be available to answer any questions you have about the research project. You can ask for any information you want. Sign the Consent Form only after you have had a chance to ask your questions and have received satisfactory answers.

If you decide to withdraw from this project, please notify the researcher. This notice will allow the researcher to inform you if there are any health risks or special requirements linked to withdrawing.

5. Queries or Concerns

Should you have any queries regarding the progress or conduct of this research, you can contact the principal researcher:

Zhen Lu (Jane)
Faculty of Business, University of Southern Queensland
Address: Unit 103C, 536-571 West Street, Toowoomba QLD 4350
Ph: +61 7 4631 5599
Mobile: +61 421192872
Email: Zhen.Lu@usq.edu.au

If you have any ethical concerns with how the research is being conducted or any queries about your rights as a participant please feel free to contact the University of Southern Queensland Ethics Officer on the following details.

Ethics and Research Integrity Officer
Office of Research and Higher Degrees
University of Southern Queensland
West Street, Toowoomba 4350
Ph: +61 7 4631 2690
Email: *ethics@usq.edu.au*

Appendix 8 Consent sheet

University of Southern Queensland

AUSTRALIA

The University of Southern Queensland

Consent Form

TO: Participants

Full Project Title: Emissions Trading in China: Lessons from Taiyuan city

Student Researcher: Zhen (Jane) Lu

- I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential.
- If the interview will be audio taped, I understand that the tape will be retained and locked in the filing cabinet for 5 years and will not be accessible to any other person except the researcher.
- I confirm that I am over 18 years of age.

Please advise the following information and sign the sheet:

Interview form: face-to-face interview ( ) telephone interview ( )

Interview time…………………………………………….

Interview place………………………………………….

Name of participant……………………………………………………………......

Signed……………………………………………………**Date**………………………..

If you have any ethical concerns with how the research is being conducted or any queries about your rights as a participant please feel free to contact the University of Southern Queensland Ethics Officer on the following details.

Ethics and Research Integrity Officer
Office of Research and Higher Degrees
University of Southern Queensland
West Street, Toowoomba 4350
Ph: +61 7 4631 2690
Email: ***ethics@usq.edu.au***

Appendix 9 Profile of coded enterprises and coded managers

Coded Enterprise	Enterprise Property	Industry	Total Assets (US$ million, US$1= RMB¥6.5)	SO_2 Emission Permits in 2007 (t)	Coded Manager
EN1	State-owned	Firepower generator	1967	30000	MA1
EN2	State-owned	Smelting and pressing of ferrous metals	6086	13000	MA2
EN3	State-owned	Firepower generator	303	7500	MA3
EN4	State-owned	Coal mining and dressing and firepower generator	6323	3300	MA4
EN5	State-owned	Coal mining and dressing and production and supply of gas	1184	1952	MA5
EN6	State-owned	Firepower generator	31	800	MA6
EN7	State-owned	Raw chemical materials and chemical products	863	780	MA7
EN8	State-owned	Special purpose equipment	2246	720	MA8
EN9	Joint venture	Smelting and pressing of ferrous metals	127	280	MA9
EN10	Provincial-owned	Ordinary machinery	88	240	MA10
EN11	Private	Concrete manufacturing	15	236	MA11
EN12	State-owned	Special purpose equipment	1108	150	MA12
EN13	State-owned	Concrete manufacturing	185	135	MA13
EN14	Joint venture	Rubber products	121	128.65	MA14
EN15	Collective-owned	Beverage manufacturing	55	114	MA15
EN16	State-owned	Concrete manufacturing	13	110	MA16
EN17	Joint venture	Beverage manufacturing	3	54.3	MA17
EN18	State-owned	Electronic and communications equipment	17	49	MA18
EN19	State-owned	Ordinary machinery	34	42.22	MA19
EN20	State-owned	Special purpose equipment	123	35	MA20

Appendix 10 Ethical clearance

USQ
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OFFICE OF RESEARCH AND HIGHER DEGREES
William Farmer
Ethics Officer
PHONE (07) 4631 2690 | FAX (07) 46311995
EMAIL will.farmer@usq.edu.au

Friday, 7 May 2010

Zhen Lu
Unit103C, 537-561West Street
Toowoomba QLD 4350

Dear Zhen,

Thankyou for submitting your project below for human ethics clearance. The USQ Fast Track Human Research Ethics Committee (FTHREC) assessed your application and agreed that your proposal meets the requirements of the *National Statement on Ethical Conduct in Human Research*. Your project has been endorsed and full ethics approval granted.

Project Title	Emissions Trading in China: Lessons from Taiyuan City
Approval no	H10REA085
Period of Approval	07/05/2010 – 07/05/2011
FTHREC Decision	**Approved as submitted**

The standard conditions of this approval are:

(a) conduct the project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments made to the proposal required by the HREC;
(b) advise the HREC (email: ethics@usq.edu.au) immediately if any complaints or expressions of concern are raised, or any other issue in relation to the project which may warrant review of ethics approval of the project;
(c) make submission to the HREC for approval of any amendments, or modifications to the approved project before implementing such changes;
(d) in the event you require an extension of ethics approval for this project, please make written application in advance of the end-date of this approval;
(e) provide the HREC with a written "Annual Progress Report" for every year of approval. The first progress report is due 12 months after the start date of this approval (by **07/05/2011**);
(f) provide the HREC with a written "Final Report" when the project is complete;
(g) if the project is discontinued, advise the HREC in writing of the discontinuation.

For (c) to (f) proformas are available on the USQ ethics website: http://www.usq.edu.au/research/ethicsbio/human

Please note that failure to comply with the conditions of approval and the *National Statement on Ethical Conduct in Human Research* may result in withdrawal of approval for the project.

You may now commence your project. I wish you all the best for the conduct of the project

Yours sincerely

Helen Phillips
Ethics Officer
Office of Research and Higher Degrees

Appendix 11 Data source for the 2007 China social accounting matrix

Row account	Column account	Included items and data source
1. Activity	2. Commodity	Domestic production, domestic sales =Total production – Export, Row margin
	9. Foreign countries	Input-Output Table of China in 2007(I/O table 2007), Export
	10. Total	I/O table 2007, Total production
2. Commodity	1. Activity	I/O table 2007, Total intermediate input
	5. Household	I/O table 2007, Total household consumption
	7. Government	I/O table 2007, Government expenditure
	8. Saving-investment	I/O table 2007, Gross capital formation
	10. Total	Total demand= sum of all the items in the row
3. Labour	1. Activity	I/O table 2007, Wages & salaries
	10. Total	Labour factor income = sum of all the items in the row
4.Capital	1. Activity	I/O table 2007, Value-added capital=Depreciation of fixed capital + Gross operating surplus
	10.Total	Capital factor income= sum of all the items in the row
5.Household	3. Labour	I/O table 2007, Wages & salaries
	4. Capital	China Statistical Yearbook 2009~ Funds Flow Statement 2007(Actual Objects Trading), The income that households get from the capital factor = Interest + Dividend + Land rent + Others
	6. Enterprise	Row margin
	7.Government	China Statistical Yearbook 2009~ Funds Flow Statement 2007(Actual Objects Trading) Transfer payment for households from government = Social insurance benefits + Social financial subsidy + Other transfers
	10. Total	Households total income= Households total expenditure
6. Enterprise	4. Capital	I/O table 2007, Enterprise capital income, Column margin
	7.Government	Transfer payment for enterprises from government, column margin
	10. Total	Enterprises total income= sum of all the items in the row
7. Government	1. Activity	I/O table 2007, Production tax (indirect tax)
	2. Commodity	China Financial Yearbook 2008, Tariff
	5. Household	China Statistical Yearbook 2009~ Funds Flow Statement 2007 (Actual Objects Trading), Individual income tax + Social insurance payment
	6. Enterprise	China Financial Yearbook 2008, Enterprise income tax
	9. Foreign countries	Transfer payment for government from foreign countries, Column margin

	10. Total	Government total income= sum of all the items in the row
8. Saving-investment	5. Household	China Statistical Yearbook 2009~ Funds Flow Statement 2007 (Actual Objects Trading), Households saving
	6. Enterprise	Enterprise saving, Column margin
	7. Government	Government saving, Column margin
	9. Foreign countries	China Statistical Yearbook 2009~ Funds Flow Statement 2007 (Actual Objects Trading), Saving in foreign countries
	10. Total	Total saving = Total investment
9. Foreign countries	2. Commodity	I/O table 2007, Import
	10. Total	Total foreign exchange expenditure = sum of all the items in the row
10. Total	1. Activity	Total input = Total production
	2. Commodity	Total supply = Total demand
	3. Labour	Labour factor expenditure = Labour factor income
	4. Capital	Capital factor expenditure = Capital factor income
	5. Household	Household consumption = sum of all the items in the column
	6. Enterprise	Enterprise expenditure = Enterprise income
	7. Government	Government expenditure = Government income
	8. Saving-investment	Total investment = Total saving
	9. Foreign countries	Total foreign exchange income = Total foreign exchange expenditure

Note**:** Some of the data in the 2007 China social accounting matrix (SAM) is different from the origin data due to the requirement of the equilibrium of the SAM table.

Appendix 12 Data source for all the parameters (including the exogenous variables)

Calibrated Parameters (including exogenous variables)	Implications of the variables	Data source
α_i^c	Transforming coefficient in the NG-oil mix function of sector i	Calibrated based on the benchmark data set- 2007 SAM table of China
α_i^f	Transforming coefficient in the fossil energy mix function of sector i	
α_i^s	Transforming coefficient in the electricity function of sector i	
α_i^e	Transforming coefficient in the energy mix function of sector i	
α_i^n	Transforming coefficient in the capital-energy mix function for sector i	
α_i^m	Transforming coefficient in the labour-capital-energy mix function for sector i	
α_i^t	Transforming coefficient in the CET function of sector i	
α_j^q	Transforming coefficient in the Armington function of commodity j	
δ_i^c	Share of natural gas in the NG-oil mix function of sector i	
δ_i^f	Share of NG-oil mix in the fossil energy mix function of sector i	
δ_i^s	Share of thermal power in the electricity function of sector i	
δ_i^e	Share of fossil energy in the energy mix function of sector i	
δ_i^n	Share of capital in the capital-energy mix function of sector i	
δ_i^m	Share of labour in the labour-capital-energy mix function of sector i	
δ_i^t	Share parameter in the CET function of sector i	
δ_j^q	Share parameter in the Armington function of commodity j	
α_{ji}	The intermediate input of j for each unit of output in sector i	
tk	Capital value-added tax rate	
tl	Labour value-added tax rate	
ti_h	Individual income tax rate	
ti_{ent}	Enterprise income tax rate	
tm_j	Import tariff rate of commodity j	
pwm_j	World price of imports of commodity j (in US$)	
pwe_i	World price of exports in sector i (in US$)	
$shif_{hk}$	Share of total capital income for households	

$shrh_j$	Share parameter of household expenditure on commodity j	
$transfr_{hg}$	Transfer payment from government to households	
$transfr_{eg}$	Transfer payment from the government to enterprises	
$transfr_{he}$	Transfer payment from enterprises to households	
$transfr_{gf}$	Net foreign borrowing	
mpc	Marginal propensity of consumption	
$\overline{QINV}_j$	The quantity investment of commodity j	
$\overline{QG}_j$	Government purchase of commodity j (in quantity)	
$\overline{FASV}$	Saving in foreign countries	
$\overline{HE}_j$	Household consumption of energy type j (in quantity)	
$\overline{QLS}$	Total available labour force	
$\overline{QKS}$	Total available capital stock	
$\overline{PGDP}$	Price index of GDP	Basic price in the model
Exogenous Parameters	**Implications of the variables**	**Data source**
ρ_i^c	Substitution parameter between natural gas and oil in sector i	Wissema & Dellink (2007, p. 6)
ρ_i^f	Substitution parameter between NG-oil mix and coal in sector i	Wissema & Dellink (2007, p. 6)
ρ_i^s	Substitution parameter between thermal power and clean energy in sector i	Wissema & Dellink (2007, p. 6)
ρ_i^e	Substitution parameter between fossil energy and electricity in sector i	(Wissema & Dellink 2007, p. 6)
ρ_i^n	Substitution parameter between capital and energy in sector i	He et al. (2002, p. 45)
ρ_i^m	Substitution parameter between labour and capital-energy mix in sector i	He et al. (2002, p. 45)
ρ_i^t	Substitution parameter between domestic consumption and exports in sector i	He et al. (2002, p. 46)
ρ_j^q	Substitution parameter between domestic supply and imports of commodity j	He et al. (2002, p. 46)
$shif_{hg}$	Ratio of the carbon tax revenue redistributed to households	Set by the researcher, different scenarios
em_j	Carbon emissions coefficient of energy type j	Zheng & Fan (1999, p. 134)
μ_j	Conversion coefficient of energy type j	Zheng & Fan (1999, p. 134)
tc	Carbon tax rate, expressed as a fixed amount of Chinese currency per ton of CO_2 emissions	Set by the researcher, different scenarios

Appendix 13 The value of parameters set exogenously

Activities (Commodities)	ρ_i^c	ρ_i^f	ρ_i^s	ρ_i^e	ρ_i^n	ρ_i^m	ρ_i^t	ρ_j^q	em_j	μ_j
Agriculture	0.5	-1	0.9	-9	-2.333	-0.099	0.8	0.667		
Heavy industry	0.5	-1	0.9	-9	-2.333	-0.099	0.8	0.667		
Light industry	0.5	-1	0.9	-9	-2.333	-0.099	0.8	0.667		
Transport and communication	0.5	-1	0.9	-9	-2.333	-0.099	0.75	0.5		
Construction	0.5	-1	0.9	-9	-2.333	-0.099	0.75	0.5		
Services	0.5	-1	0.9	-9	-2.333	-0.099	0.75	0.5		
Coal	0.5	-1	0.9	-9	-2.333	-0.099	0.75	0.667	0.54	0.973
Oil	0.5	-1	0.9	-9	-2.333	-0.099	0.75	0.667	0.84	0.973
Natural gas	0.5	-1	0.9	-9	-2.333	-0.099	0.75	0.667	0.0006	0.973
Electricity	0.5	-1	0.9	-9	-2.333	-0.099	-1	-0.111	0	0
Clean energy	0.5	-1	0.9	-9	-2.333	-0.099	-1*	-0.111*	0	0

* The substitution elasticity in CET function and Armington function of clean energy sector is assumed to be the same as that of the electricity sector.

Sources: Wissema & Dellink (2007), He et al. (2002) and Zheng & Fan (1999)