Project in Support of the China National Development Reform Commission's State Information Center, in cooperation with Monash University's Centre of Policy Studies, Melbourne

Market mechanisms for China's carbon emission reductions: Economics, modelling and international experience

Research Papers and Key Findings

April 2013

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Preface

This publication, *Market mechanisms for China's carbon emission reductions: Economics, modelling and international experience*, is a collection of policy research papers and key findings and recommendations, which is the result of the final stage of a cooperative carbon market research, design and capacity building project between China and Australia. The project was funded by the Australian Department of Climate Change and Energy Efficiency (DCCEE).[1] It was implemented by Monash University's Centre of Policy Studies (Monash/CoPS), Melbourne, in cooperation with and in support of the China State Information Centre (SIC) under the National Development and Reform Commission (NDRC) in Beijing.

The report is the product of twelve months (between April 2012 and April 2013) of economic modeling capacity building at SIC, careful joint research, analysis, expert studies, study tours and technical missions to Australia, consultations, advisory support to and exchanges with China's central government policy makers, energy and economic research institutes and the Shenzhen emissions trading scheme (ETS) pilot in China, and domestic and international workshops in China. The research project assisted SIC to strengthen its Computable General Equilibrium (CGE) inter-regional carbon market economic modelling tools and expertise, in cooperation with Monash/CoPS, and undertake a series of quantitative and qualitative research/analytical studies in collaboration with Australia's leading climate change economists from the Garnaut Climate Change Review.

The project evaluated policy options for cost-effective market mechanisms (emissions trading/carbon pricing) for carbon emission abatement in China. Qualitative analysis of market instrument choice and policy design on the basis of economic principles and international experience were undertaken. These studies and the technical advice offered were designed to stimulate informed carbon pricing policy discussions in China, and inform Chinese Government policy-making to develop frameworks for a national carbon emissions trading system by 2016, for national implementation during China's 13th Five Year Plan (2016-2020).

A Chinese language version of this publication is under preparation in Beijing by the State Information Center. This will be published by the China Social Science Academic Press, Beijing, in mid-2013, for distribution to policy-makers in the Chinese government and its agencies, local ETS pilot authorities, and energy/economic policy research and academic institutions in China.

1 On March 26 2013, DCCEE was abolished, and its climate change functions were transferred to the new Australian Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, Canberra

Acknowledgments

This report on China's market mechanism options for carbon emissions abatement is the final product of twelve months of planning, capacity building, research and analysis work and exchanges by a collaborative group of carbon market design experts and economic modellers in both China and Australia. The project's research work, with its scale and complexity, including the task of strengthening the State Information Center's carbon market modeling tools and expertise, could only be completed through the contributions of many experts, institutions and organizations in both China and Australia.

The research project had the good fortune of being supported in China by the project's government economic policy research partner, the NDRC's State Information Center and staff and experts from its Economic Forecasting Department, and in turn by officials and experts from the State Council's National Energy Administration, NDRC's Department of Climate Change, the National Statistical Bureau, the Shenzhen ETS pilot authorities and Shenzhen Municipal Government, other ETS pilot authorities and advisers, as well as economic and energy experts from Tsinghua University's Institute of Energy, Economics and Environment, the Chinese Academy of Sciences, the Chinese Academy of Social Sciences, NDRC's Energy Research Institute, and the State Council's Development Research Center.

Special mention should be made of the research and analytical contributions and comments provided by SIC senior research fellow Mr. Zhang Yaxiong, Drs. Li Jifeng and Liu Yu of SIC, and Associate Professors Drs. Teng Fei and Gu Alun, and Prof Zhang Xiliang of Tsinghua University

The project's implementation and its final research report had been the beneficiary of the exceptional Australian skills and professionalism. SIC's Computable General Equilibrium (CGE) inter-regional China carbon market economic model was built with the support of Monash University's Centre of Policy Studies. Inter-regional model advice was provided by Prof Philip Adams, Prof Peter Dixon, and Dr. Glyn Wittwer. Monash/CoPS had previously provided carbon emissions trading modelling to the Garnaut Climate Change Review and the Australian Treasury.

Under this project, CoPS further strengthened SIC's expertise in policy simulation and in undertaking quantitative analysis of China's carbon trading options and the benefits of including China's electricity sector in nationwide emissions trading. Analytical work on China's coal-fired electricity plant efficiency and project administrative support was provided by Dr. Yinhua Mai and Mr. Shenghao Feng.

Extensive qualitative analysis and strategic and technical advice was provided to the project and SIC by Australia's leading climate change economists from the Garnaut Climate Change Review. Notable were Prof Ross Garnaut from Melbourne University, who provided the keynote presentation and important concluding remarks at the project's Beijing International Workshop in January 2013, and Dr. Frank Jotzo, Director of the Centre of Climate Economic and Policy, Crawford School of Public Policy, Australian National University, Canberra.

Dr. Jotzo's research contributions examined details of key features of a nationwide ETS and carbon price design options in China, taking into consideration China's unique economic and institutional circumstances. He also drew on lessons from international practice, especially Australian and European experience. Special thanks are due to Dr. Jotzo for his professionalism in providing outstanding technical advice and wise direction to the project, and valuable ongoing guidance to SIC. The project's implementation and final report has benefited greatly from his collaboration.

Dr. Ian Davies
Project Coordinator
Canberra, Australia

Acronyms

ANU	Australian National University
BAU	Business as Usual
CAS	China Academy of Sciences
CASS	China Academy of Social Sciences
CCEP	Centre for Climate Economics and Policy (Australian National University (ANU) Crawford School of Public Policy, Canberra)
CCS	Carbon capture and storage
CDM	Clean Development Mechanism (Kyoto Protocol)
CGE	Computable General Equilibrium model
CO_2	Carbon dioxide
CoPS	Centre of Policy Studies (Monash University/Melbourne)
CPI	Consumer price index
CSIRO	Commonwealth Science Industrial Research Organisation
DCCEE	Department of Climate Change and Energy Efficiency (Canberra)
DRC	State Council Development Research Centre
ERI	NDRC/Energy Research Institute
ETS	Emissions Trading Scheme
GDP	Gross domestic product
GHG	Greenhouse g as
GTEM	Global Trade and Environmental Model
IEA	International Energy Agency
IO table	Input Output table
LCE	Low carbon economy
LLS	Large substitute small (thermal power plants)
MMRF	Monash Multi-Regional Forecasting model
Monash/CoPS	Monash University/Centre of Policy Studies, Melbourne, Australia
NCSC	National Centre for Climate Change Strategy & International Cooperation
NDRC	National Development Reform Commission
NEA	National Energy Administration
NEM	National energy market
NGAS	NSW greenhouse gas reduction scheme
NSB	National Statistical Bureau, China
OECD	Organisation of Economic Cooperation and Development
RMB	Renminbi
SAI	Small and inefficient (thermal power plants)
SCE	Standard coal equivalent
SERC	China Electricity Regulatory Commission
SIC	China State Information Centre
TERM	**T**he **E**normous **R**egional **M**odel (“bottom-up CGE model), Monash University/Centre of Policy Studies, Melbourne

TSO	Transmission systems operator
TWh	Terawatt-hour
USRGGI	Regional Greenhouse Gas Initiative (US)

China NDRC/State Information Center Carbon Market Project, in cooperation with Monash University's Centre of Policy Studies, Melbourne

Market mechanisms for China's carbon emission reductions: Economics, modelling and international experience

Executive Summary of the China Carbon Market Project Research Papers and Key Findings

Project Overview

The project is a cooperative China-Australian capacity building and policy research carbon market project, funded by the Australian Department of Climate Change and Energy Efficiency (DCCEE). [2] It was originally entitled *The design and development of cost-effective market mechanisms for carbon reduction in China*, and was undertaken between April 2012 and April 2003. The research project assisted the China State Information Centre (SIC) [3] in Beijing to build up CGE inter-regional carbon market economic modelling tools and expertise, in cooperation with Monash University's Centre of Policy Studies (Monash/CoPS), and undertake a series of quantitative and qualitative research/analytical studies in collaboration with leading Australian climate change economists from the Garnaut Climate Change Review that evaluated policy options for cost-effective market mechanisms (emissions trading/pricing) for carbon emission abatement in China. Qualitative analysis of market instrument choice and policy design on the basis of economic principles and international experience were undertaken. These studies were designed to inform Chinese Government policy-making aimed at developing a framework of a national carbon emissions trading system by 2016, for national implementation during China's 13th Five Year Plan (2016-2020).

The activities under the project involved a study tour to Australia, a modelling capacity building mission, detailed technical cooperation, workshops, consultations and advice on policy design issues (including design support to the Shenzhen emissions exchange pilot), economic research and institutional analysis of the electricity sector, a high level international workshop in Beijing (on January 31 2013 (*The design and development of cost-effective market mechanisms for carbon emissions reductions in China - Economic modelling and international experience*), and publication of carbon market research papers for the national government and pilot provinces and cities.

[2] On March 26 2013, DCCEE was abolished, and its climate change functions were transferred to the new Australian Federal Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, Canberra

[3] A central government agency under the National Development Reform Commission (NDRC). It is the Chinese government's principal economic forecasting and economic policy modelling research agency.

The China policy end-users of the project research will be the NDRC and its Department of Climate Change, the National Energy Administration, related NDRC research agencies and supporting academic institutions (eg. Tsinghua University, CASS and CAS), as well as China's two carbon emissions trading provincial pilots and five city pilots. These pilots are responsible for designing and initiating intra-regional trading markets by the end of 2013, and up-scaling local pilot/regional markets towards a nationwide market from 2016 onwards By seeking to design and adopt market-based measures, this new carbon trading and pricing system is aimed at developing a cost effective response to climate change and to ultimately assist China to transition to a more energy efficient low carbon economy.

A national emissions trading scheme for China offers very large opportunities for cost-effective climate change mitigation, and in providing support to achieve the national target of reducing carbon emission intensity by 40-45% by 2020 target relative to 2005. The anticipated adoption of market based policy instruments for emissions control is significant, in a fast-growing economy where climate change mitigation policy has been predominantly by command and control approaches, and where many aspects of energy pricing are heavily regulated. The introduction of carbon pricing would also be a catalyst for further market and industrial reforms, in particular in China's energy and electricity sectors. Through this process, China has the opportunity to move to world's best practice on carbon pricing, but it also faces challenges due to its unique regulatory and institutional environment

Project Achievements

In summary, the project achieved the following:

- Appropriate advanced inter-regional CGE *TERM* greenhouse gas/economic models were acquired, and model extension and policy simulation and research analytical skills were transferred to SIC by Monash/CoPS. SIC also learned how to undertake basic policy simulations of emissions trading scheme policy questions. This capacity now needs to be consolidated, expanded and applied to a wider range of climate change/emission reduction policy questions (under a possible new project activity).

- Policy design analysis through the project's research papers and internal and international workshop has been advanced, and is now contributing to the Chinese policy debate within government and within national research and academic circles, as evident from the NDRC/SIC Beijing International Workshop held January 31 2013.

- SIC's credibility in applying advanced inter-regional modelling of key Chinese policy questions among NDRC and other central government policy departments and agencies has been enhanced significantly, which will provide a solid base from which to further develop knowledge to undertake more accurate modelling and analysis of new national carbon pricing design features and fiscal policy questions.

- The Australian clean energy program and fixed carbon pricing experience, and price/ coverage and fiscal design elements, are better known in China as a result of this project, adding to the knowledge gained through the World Bank PMR project and the annual government-to-government technical exchanges with NDRC.

Key Project Findings

The key findings of the project's research papers, including carbon market policy recommendations, can be found in each of the research papers, and a summary of these can be found in the following section of the Executive Summary. A particularly valuable contribution to the project's high level policy recommendations and suggestions for a further research agenda can be found in Prof Ross Garnaut's concluding remarks at the NDRC-SIC Beijing International Workshop, January 31 2013. The last item of the Executive Summary lists all recommendations for follow-up carbon market research activities and new project proposals.

Listed below are a number of key observations that were highlighted in the research papers and/or commented on in discussions on high level issues at the Beijing Workshop:

(1) In recent years, China has increasingly taken on the world's largest energy and carbon emissions reduction effort, and taken on a leadership role in climate mitigation policy:

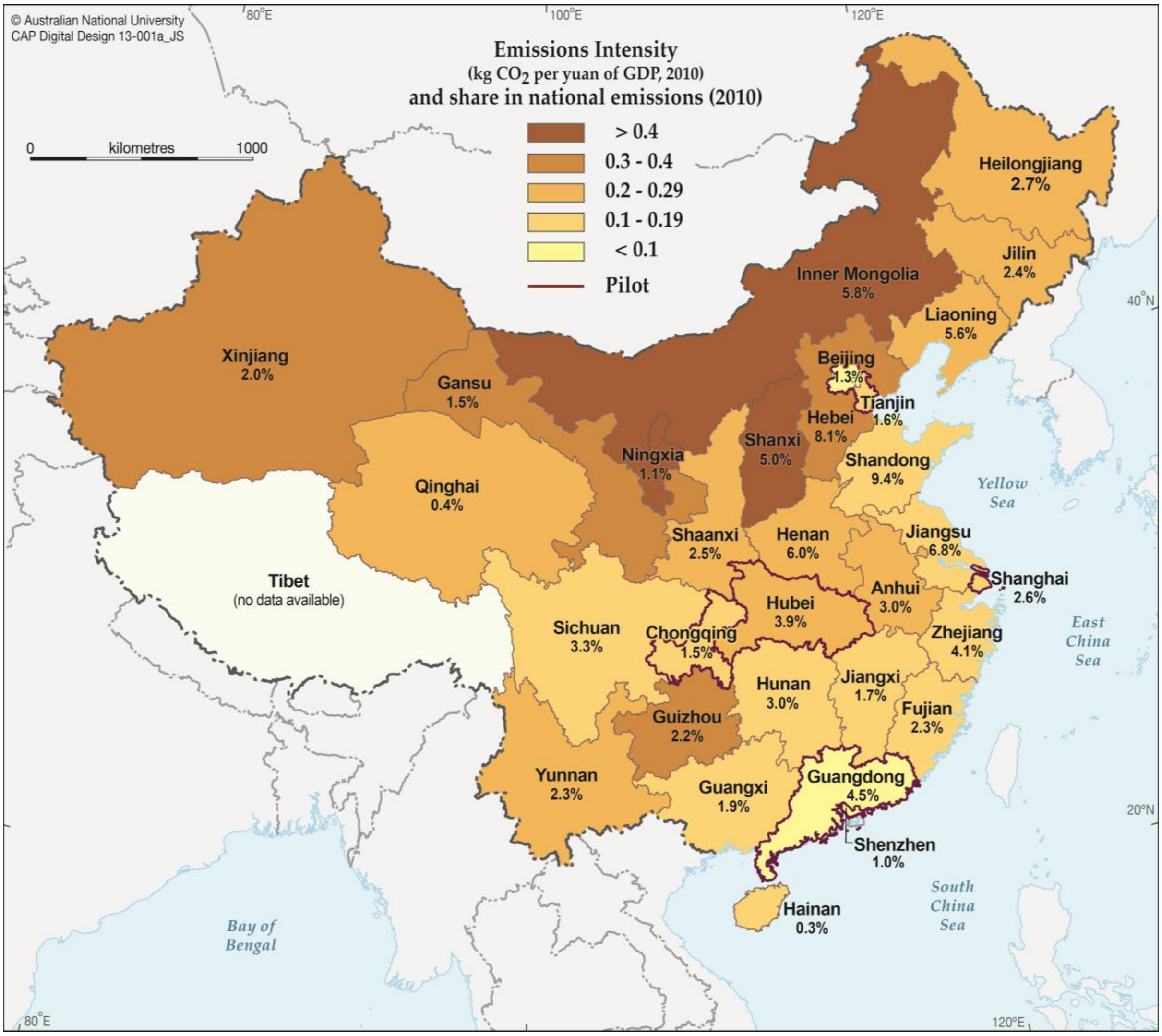
- China is well placed to achieve its national emissions intensity target for 2015 (reduction of 17% 2010-2015) and 2020 (reduction of 40-45% 2005-2020), and for emissions to peak and decline in the mid-2020s or earlier. This will be primarily achieved through the parallel actions of top-down regulatory controls and new building and vehicle codes, most notably the closure of small coal-fired power plants (80.3 GW were closed 2006-2011) and other industrial plants (mainly iron & steel, cement and non-ferrous metals) and their replacement by large scale low carbon/highly energy efficient capacity, and the incremental implementation of a carbon price, initially in seven pilot areas 2013-2015, and nationally during the 13th Five Year Plan (2016-2020)
- China's energy consumption intensity fell over the five years 2006-2011 by 24 % (and 19.1% 2006 – 2010), and fell a further 3.6% in 2012. China also announced the capping of primary energy consumption at 4.0 billion tonnes of standard coal equivalent (sce) p.a. by 2015 (compared with a consumption of 3.8 billion tonnes p.a. sce in 2012)
- China may have reached a remarkable turning point from 2012 in consumption of coal for electricity generation, which may be a forerunner of a shift to a less resource and emissions intensive phase in China's growth. Thermal power generation slowed dramatically in 2012 to an 0.6% growth compared with a total electricity generation increase of 5.7% while GDP increased 7.8% p.a.

- Newly added capacity in green power in recent years, and especially in 2012 (23 GW), in hydropower, nuclear power, wind and solar energy, has meant that China is now the world’s leading country in the installation of renewable energy capacity on an annual basis. This is a dramatic break from established trends, and is of historic importance in global terms
- China is on track to meet or exceed its renewable energy/non-fossil energy target of 11.4% of primary energy consumption in 2015, and 15% by 2020
- The context within which this accelerated transformation took place is that a major long term structural change in the economy, the energy sector, and economic growth in China had begun, facilitated by deeper economic and market/price reforms, and the impact of higher energy efficiency and a changing energy mix made possible through technological change. China’s past carbon intensive growth model (characterised by high levels of investment, manufacturing and exports, and comparatively low levels of consumption and service sector output), appears to have reversed in response to a 12th Five Year Plan (2011-2015) policy-driven rebalancing towards consumption and services (under which the service sector is planned to grow to 47% of GDP by 2015). As a result, de-coupling of economic growth from carbon emissions appears to have commenced. Ultimately, this is the key to emissions reductions and the tackling of China’s climate change problems.

(2) Market-based policy instruments, in particular carbon pricing, are poised to play an increasingly important role relative to command and control regulatory measures. They may become the key policy instrument in China’s carbon abatement effort

- China’s seven ETS pilots and NDRC have accepted that price signals are necessary for cost-effective mitigation. For details of the ETS features of the seven ETS pilots, refer to the appendix to Dr. Frank Jotzo’s research paper, Part 2
- There is increasing recognition in government and among the research community that the cost of carbon emission abatement can be lower than under alternative direct regulatory approaches, through the sound design of market-based carbon pricing and technological developments.
- In the move towards national carbon pricing under the 13th Five Year Plan, a simple carbon tax in some respects might be preferable to emissions trading if a carbon tax has better prospects of allowing revenue distribution to support a more equitable and more efficient economy compared with an ETS (where the tendency appears to be to allocate a majority of permits for free).
- More comparative studies using advanced modelling are therefore essential to assess the impact of a carbon tax with revenue distribution to support low carbon activities, reduced corporate tax and subsidies to lower income households, compared with an ETS (with free permits)

Provincial and pilot ETS map of China, showing carbon emissions intensity (kg of CO2 per RMB of GDP, and share in national emissions, 2010 data



CartoGIS, College of Asia and the Pacific, Australian National University, Canberra, Australia

- Carbon pricing should be seen in the context of economic policy reform: pricing can drive deeper economic reforms, restructuring and economic rebalancing, and can initiate fiscal and tax reform through re-distribution of carbon price revenues and fiscal transfers to poorer regions
- Effective carbon pricing in the electricity sector through price reform/ flexibility would drive wider market-based energy sector and institutional reforms and encourage greater energy conservation. Whereas there were earlier doubts that the electricity sector would be included in China's ETS, due largely to industry pressure and complexities associated with fixed power pricing, most ETS pilots' coverage will now include the electricity sector

- Carbon price determination is a big policy issue for China and Chinese ETS pilot authorities. All levels of government are concerned about price uncertainties, the potential for volatility (eg. EU ETS), the downstream impact on industry and consumers, the predictability of emissions, emission abatement responses, permit trading prices or carbon tax levels, and the ultimate costs of abatement. As a result of this project and learning of the Australian experience, there is much greater interest in government and among researchers in new policy concepts such as the design and operational detail of fixed price permit schemes and mandated price floors and ceilings

(3) Sound policy design

- Project research papers strongly recommended a broad ETS coverage, possibly with 'upstream' permits (or a carbon tax) applied to fossil fuels
- Any free permit allocations to industry should be carefully calibrated to retain renewable energy and energy conservation incentives and support for related efficiency innovations
- Assistance arrangements to emitters to upgrade and restructure: These should avoid lock-in. They should be reviewed and phased out over time (Australia's example)
- By introducing sound cost effective carbon market designs and tax/fiscal reforms, in which carbon price revenue is directed to low and middle income households to increase household consumption and to reduce business taxes, a carbon price would likely lead to reductions in regional and household inequality (a major social policy goal under the 12th Five Year Plan, 2011-2015)
- The view was expressed several times by senior Chinese academics at the project's Beijing Workshop that China was challenged by institutional complexities and problems that are associated with the transition from a pilot to a national ETS system. These obstacles, among others, would mean that the development of a sound national ETS or carbon price design would take longer than expected, and that a national ETS or national carbon price may not be legislated for and be operational until later in the 13th Five Year Plan.

(4) Findings from the quantitative modeling

- In Prof Philip Adams' (Monash/CoPS) paper, simulations using the Monash Multi-Regional Forecasting (MMRF) model of the Australian carbon price demonstrated that the overall long term (to 2030) macroeconomic impact of the ETS would be very small in the context of the policy task; international trading in emissions permits is critical for Australia; and some industries were particularly vulnerable (coal-fired power generation and the aluminium smelting), requiring some government short-term, compensation through free-allocation of permits and longer-term adjustment programs, including support for new less emission-intensive industries

- Dr. Liu Yu's (SIC) paper used the newly built bottom–up CGE China SICGE-R-CO2 inter-regional model, developed by the project, to simulate and assess the economic impact of linking the pilot carbon markets of Guangdong and Hubei Provinces, and found that there would be major efficiency gains through regional trading. A Guangdong-Hubei linked carbon market would dramatically reduce (more than 40%) the cost of overall regional emissions reductions compared with separate schemes. This would require Guangdong to purchase 60% of its emission permits from Hubei, and require Hubei to undertake a doubling of its earlier planned emission reduction effort. It also found that the more participants in carbon trading, the lower the emission abatement cost.

- In Dr. Li Jifeng's paper, the economic impact of a carbon price under China's existing regulated electricity price system was simulated using SIC's SICGE model, and assumed an RMB 100/tCO2 price ($A 16/t). The key findings were that emissions were reduced (6.8%) even if the electricity price was unchanged, and that emission abatement scenarios where the electricity price was flexible were even more economically efficient. Recycling ETS revenue to reduce sales taxes (short term) and production taxes (longer term) promoted economic efficiency.

- In Shenghao Feng/Dr. Yinhua Mai's paper, the economic, financial, and environmental impact of China's coal-fired electricity efficiency improvements were analysed, and the most-likely and other scenarios of this efficiency improvement (more efficient technologies, larger plants) in future years were simulated. The analyses showed that investment in improved coal-fired electric plant efficiency led to higher GDP (0.15% over 4 years) and lower CO2 emissions (1.2% per year in the long run), higher employment in the short run, higher capital stock in the long run, and that the net present value of future higher GDP and lower emissions was greater than the up-front investment costs.

List of summaries of research papers and their key findings/ recommendations, workshop concluding remarks, and recommendations for follow-up carbon market research activities and new project proposals

1. Emissions trading in China - Principles, design options and lessons from international practice (Dr. Frank Jotzo)
2. Insurance against catastrophic climate change: How much will an emissions trading scheme cost Australia? (Prof Philip Adams)
3. The economic impact of linking the pilot carbon markets of Guangdong and Hubei Provinces: A Bottom – Up CGE China SICGE-R-CO2 Model Analysis (Dr. Liu Yu, Cai Songfeng and Zhang Yaxiong)
4. An analysis of the economic impact of a carbon price under China's regulated electricity price system – Application of the China SICGE model (Dr. Li Jifeng, Wang Lixin, and Zhang Yaxiong)
5. Direct emissions entitlement and indirect emissions entitlement: Recommendations to the pilot regions' carbon markets in China (Dr. Li Jifeng and Zhang Yaxiong)
6. Institutional analysis of introducing an emissions trading system to China's electric power industry (Dr. Teng Fei, Associate Professor Gu Alun, and Mr. Lu Zhiqiang)
7. Increasing China's coal-fired power generation efficiency – Impact on China's carbon intensity and the broader economy to 2020 (Mr. Shenghao Feng and Dr. Yinhua Mai)
8. Concluding remarks and recommendations made by Professor Ross Garnaut, at the NDRC-SIC Carbon Market Beijing International Workshop, January 31 2013 (The design and development of cost-effective market mechanisms for carbon emissions reductions in China - Economic modelling and international experience)
9. Recommendations for follow-up carbon market research activities and new project proposals

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Paper 1: Emissions trading in China - Principles, design options, and lessons from international practice

Dr. Frank Jotzo, Australian National University, Canberra, Australia

China has ambitious goals to limit the growth of greenhouse gas emissions. China's energy and climate policy to date has relied largely on a direct regulatory top-down approach. However market-based instruments – in particular putting a price on emissions – generally offers the best prospect to achieve cost-effective climate change mitigation. China is considering a national emission trading scheme, and proposals for a national carbon tax have also been raised, as part of a suite of policies to reduce the growth of greenhouse gas emissions.

As a first step, several pilot emissions trading schemes are in preparation, and some are expected to go into initial trial operation in 2013. A move towards market based policy instruments is significant, in a fast-growing economy where command and control approaches to policy have dominated, and where many aspects of energy pricing are heavily regulated. China has the opportunity to move to world best practice on carbon pricing, and if successful could encourage other countries to emulate the experience.

The paper examines policy design issues for national emissions pricing in China, through emissions trading, or alternatively a carbon tax. The paper analyses issues of policy design, in the light of economic principles, China's circumstances and Australian and European experiences. It suggests options for coverage, ways of setting an emissions cap in the context of the national intensity target, options for price management (whether and how to manage prices in emissions markets), approaches to permit allocation and revenue use, and discusses the special issues in China arising for the electricity sector in the context of regulated prices.

The paper draws on experience in existing carbon pricing schemes, in particular the Australian carbon pricing scheme and the European Union's emissions trading scheme. Each section includes a consideration of principles on specific issues of policy design, a brief summary of relevant international experiences, a brief indication of future research needs, and a discussion of implications for a potential future Chinese national ETS. The analysis is to a large extent equally applicable to pilot emissions trading schemes.

The paper finds that:

- Market based instruments for climate change mitigation should be seen in the broader context of economic policy reform and fiscal/tax reform. These new approaches offer opportunities to support broader reform goals involving economic and market policy reform, energy policy, price liberalisation, and environment and climate policy.

- The model-based estimates of the economic cost of abatement in China assume that least-cost policy instruments – such as economy-wide emissions pricing – are implemented. Achieving this in practice requires carefully designed policy frameworks.

- Broad coverage of carbon pricing can improve cost effectiveness. Not all emitters need to be included directly in emissions trading. Upstream permit liability and equivalent emissions charges or taxes may allow increasing coverage while minimising transaction costs and administrative complexity. Upstream approaches in particular can minimise difficulties in monitoring, reporting and verification (MRV) of companies' emissions, which is a necessary underpinning of effective carbon pricing

- China's dynamic growth and uncertainty about the response of emissions to carbon pricing presents challenges for translating the national intensity target into an absolute cap on emissions in a national emissions trading scheme. The cap (amount of permits issued) may need periodic adjustment in light of GDP growth.

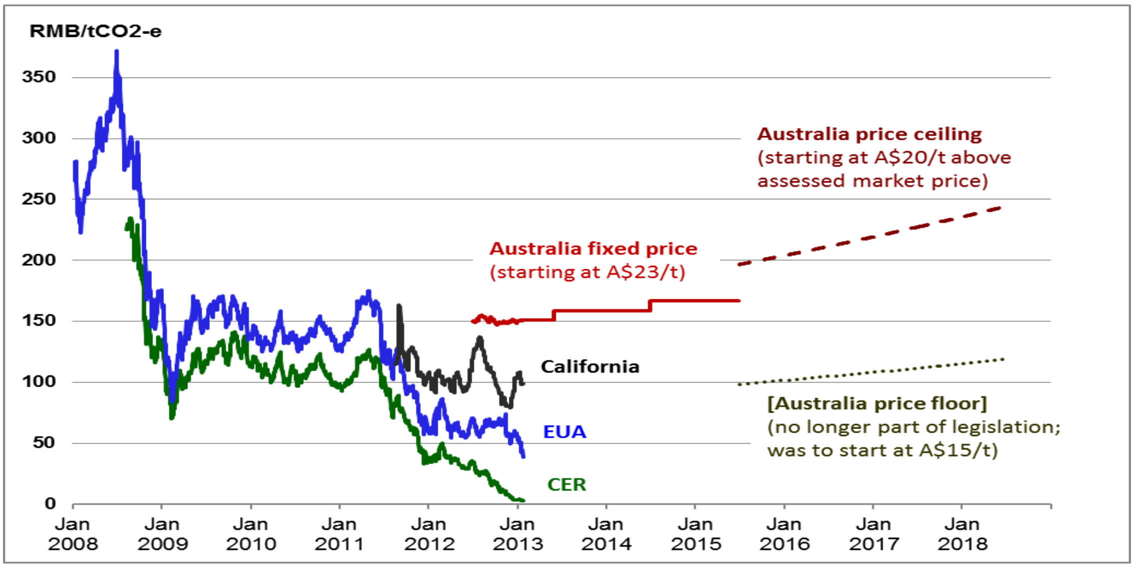
- Conversely, a carbon tax may result in greater or lesser abatement than anticipated.

- Market based instruments for climate change mitigation should be seen in the broader context of economic policy reform, fiscal/tax reform, energy price reform, and environmental and climate policy.

- Achieving emissions reductions at least cost, as typically assumed in economic modelling, in practice requires carefully designed policy frameworks.

- Under a pure trading scheme there would be significant uncertainty about price levels, and potentially large price variability. It is desirable to manage prices at least in the early phases of emissions trading. This could be achieved in a variety of ways. Within a trading scheme, the price can be constrained by a price floor and ceiling; or the permit supply could be made variable to respond to market prices. A phased approach may be appropriate, possibly starting with a fixed price, moving to a hybrid model switching to internationally integrated trading if and when conditions are appropriate. Another option is a fixed price model, where government sells permits at a predetermined price; a transition from a fixed price model to a market based trading scheme would be straightforward. A straight carbon tax may also be a viable option. It would provide short term price certainty. However, the level may need to be revised in future, and the same considerations for coverage, assistance to renewable and industry more generally, and energy sector and pricing reform, would apply.

Carbon prices and options for price management



- Assistance to industry in the form of free permits (or tax exemptions) to industry needs to be carefully calibrated, in view of incentive effects, the opportunity costs to the budget, and risk of lock-in of assistance arrangements. It is best practice for governments to retain a substantial share of the overall value of emissions permits, and in turn use the revenue to support households, reduce other taxes, or finance other policy measures.

- Traditional arguments about ‘carbon leakage’ are generally unlikely to warrant large payments to domestic industries because of China’s likely strong influence on global commodity prices. Where free permits and other assistance are given to industry, incentives to reduce emissions need to be preserved, and provisions for review and phase-out of industry assistance are advisable. The same issues apply for a carbon tax, which may see industry associations lobby for partial exemptions.

- Establishing an effective carbon price in the electricity sector is possibly the greatest challenge for market-based climate change mitigation in China. Carbon pricing in electricity supply and demand is necessary for an overall cost-effective response, but presents complex issues for mechanism design and policy implementation. This is because of the interplay with existing regulatory structures in the energy sector, in particular fixed electricity supply prices and mandated dispatch schedules. There are ways to make carbon pricing at least partly effective ahead of comprehensive energy sector reform, by providing appropriate incentives to electricity generators and – possibly separately – to electricity users. Ultimately however, energy sector reform leading to market-based energy pricing is needed.

Paper 2: Insurance against catastrophic climate change: How much will an emissions trading scheme cost Australia?

Prof Philip Adams, Director, Centre of Policy Studies, Monash University, Melbourne, Australia

There is now compelling advice from the scientific community that a sharp cut in world green house gas emissions would substantially reduce the risk of catastrophic climate change over the next century. Cutting greenhouse gas emissions is like buying an insurance policy: we incur a cost (a loss in GDP) to reduce a risk (catastrophic climate change). In any insurance decision, the cost matters. If a worthwhile reduction in risk costs 50 per cent of income, then living with the risk may be preferable. But if it costs 1 per cent of income, then taking the insurance policy may be the best option.

The purpose of this research paper is to evaluate the possible cost in the context of an emissions trading scheme (ETS) for Australia, consistent with that established in July 2012 as part of the Australian government’s *Clean Energy Plan* (www.cleanenergyfuture.gov.au/clean-energy-future/our-plan/). The analysis is based on simulations of the Monash Multi-Regional Forecasting (MMRF) model. The Australian carbon price framework is assumed to be part of a global ETS. Over time, the global ETS becomes the dominant greenhouse abatement policy for all countries including Australia. It sets the price for carbon permits and allocates the number of permits available to each country.

A number of key findings emerge from the MMRF simulations of the effects of the ETS policy in Australia:

1. Domestic abatement efforts fall well short of targeted abatement (5 per cent below 2000 levels by 2020 and 80 per cent below 2000 levels by 2050), requiring significant amounts of emissions permits to be purchased abroad.
2. Despite the requirement for deep cuts in emissions, the ETS reduces Australia's GDP by 1.1 per cent relative to the base-case level by 2030. To put this into context, in the base case real GDP grows at an average annual rate of 2.60 per cent between 2010 and 2030. With the ETS imposed, average annual growth falls to 2.55 per cent.
3. The negative impact on real household consumption (the preferred measure of national welfare) is a little higher (1.7 per cent relative to its base-case level in 2030), reflecting the need to import permits. International trading in emissions units is therefore important for Australia.
4. The national macroeconomic impact of the ETS is described as **very small** in the context of the policy task.
5. However, the very small overall economic impact does not carry through to the industry and state/territory levels, where some industries and regions were particularly vulnerable. Good examples are coal-fired power generation and the aluminium smelting industry, and their associated regions. In these cases the government might consider, in the short-term, compensation through free-allocation of permits, and in the long-term, adjustment programs focusing on re-training and the establishment of new less emission-intensive industries.

The need for detail, and the need for a suite of models, international, national and sectoral/ regional, is highlighted throughout the analysis. For example, a suitably detailed treatment of electricity supply is provided by linking CoPS' model with *Frontier Economic's* detailed bottom-up model of the stationary energy sector. Similarly, necessary detail on the effects of the global ETS on Australia's international trading conditions is provided by linking with a multi-country model.

Paper No. 3: The economic impact of linking the pilot carbon markets of Guangdong and Hubei Provinces: A Bottom–Up CGE China SICGE-R-CO2 Model Analysis

Dr. Liu Yu, Cai Songfeng and Zhang Yaxiong
Department of Economic Forecasting, State Information Center, Beijing

This research paper investigates the economic impact of linking China's two provincial pilot ETS markets of Guangdong and Hubei provinces, so as to gain insights into the benefits and obstacles of linking domestic carbon markets in China. The most significant benefit of linking carbon markets is derived from higher economic efficiency, as ETS schemes allow emissions abatement to be carried out in lower cost regions, which enhance the welfare of both trading parties.

The study utilized the SICGE-R-CO2 model (a bottom-up multi-regional static Computable General Equilibrium model with a carbon dioxide emission permit trading module, developed by the State Information Center under this project in cooperation with Monash University's Centre of Policy Studies), to simulate emissions cost reductions and the economic impact of Guangdong's and Hubei's independent emissions trading efforts by engaging in cross-provincial carbon trading

The analysis concluded that linking carbon trading markets in China can efficiently reduce carbon abatement costs of the regions involved. It was found that with a carbon price in Guangdong and Hubei respectively of RMB 102.9/tonne of CO2 and RMB 14.8/tonne of CO2, the average emissions reduction cost for the two regions, if the two provinces took actions independently, would be RMB 972.4/tonne of carbon dioxide. However, in a linked carbon market where Guangdong buys from Hubei 23 million tonnes of emission permits (RMB 824 million), the average carbon price would drop to RMB 35.9/tonne of carbon dioxide and the overall emissions reduction costs would be RMB 567.9/tonne of carbon dioxide (the overall efficiency gains would amount to a 41% reductions in abatement costs).

This trading scenario is based on Guangdong province's purchase of emission permits from Hubei, as emission abatement costs in Guangdong were higher. As only 40% of emissions reductions in Guangdong were achieved within Guangdong, the province could only achieve its overall emission abatement target by purchasing 60% of its emissions permit requirements from Hubei province. This would require Hubei province to achieve an actual emission reduction which would be double that originally targeted (8.9%).

From the perspective of the industrial sector, the research found that output reductions from high emitters would be the main driving force for emissions reduction, while the substitution effect between different fuels would be limited. From a macroeconomic viewpoint, a carbon price and a carbon market would exert a modest negative impact on long term economic growth, especially on investment, but its inflation impact would be negligible. Although Hubei province's GDP (a seller of emission permits to Guangdong) would be reduced a little, the province's welfare component would be improved. From the perspective of specific industrial sectors, industries with high emissions such as electric power, non-metallic mineral products, non-metallic mining and dressing, metal smelting and rolling, and chemicals would be heavily impacted, but the services sector would be largely unaffected.

Inter-regional modelling research conclusions

The following conclusions can be drawn from the inter-regional modeling research:

(1) A Guangdong-Hubei linked carbon market would dramatically reduce the cost of overall regional emissions reductions. The more participants in carbon trading, the lower the emission abatement cost would be. Therefore, it is recommended that China should actively promote regional carbon markets and list these as a key emissions reduction approach during the 12th Five-Year Plan period.

(2) Guangdong and Hubei should focus more on key industrial sectors and employ appropriate but different long-term and short-term energy efficiency and emission reduction measures. Since most carbon emissions in the two provinces are highly concentrated in certain industries, reducing emissions in these specific emission intensive industries should be considered a top policy priority by government.

In the short term, major regulatory measures should be introduced to limit the capacity of emission intensive industries, and to substitute emissions intense energy through the rapid expansion of non-fossil fuel energy sources, but these regulatory measures should play a supplementary role. In the long run, a market-based pricing mechanism for energy products should be given full play to drive restructuring of the energy mix. The regulatory measures and the pricing mechanism should complement each other.

(3) Carbon trading will have quite different impacts on the trading parties. As a buyer of emission permits, Guangdong will enjoy lower emission reduction costs in a trading scenario, while the abatement costs in Hubei will increase. Due to uneven regional development in China, emission abatement costs in enterprises in different regions will differ. Therefore, project and enterprise cooperation is recommended. Enterprises with advanced technologies and equipment and abundant capital in regions of high emissions reduction cost should be encouraged to invest in less developed areas where costs are low, which will ensure both economic development and emission reduction.

(4) Carbon markets are ultimately beneficial to industrial restructuring. Energy intensive and emission intensive industries might be affected, some severely, but the services or tertiary sector is largely unaffected. This will help adjust and optimize regional industrial structures, and transform China’s development pattern.

Future research work

In regard to future research work, it is recommended first that the State Information Center (SIC) should strengthen cooperation with regional ETS pilots, with the aim to introduce more detailed data to its SICGE-R-CO2 inter-regional model. Different types of emission permit allocation (free allocation or auction) will be evaluated, as will industrial enterprise coverage in carbon trading, making sure that an emissions cap or quota is established for each industry. Distribution of carbon trading revenue would also be examined in greater detail to determine the impact on the economy and its various sectors including renewable energy, and more actual trading and emission reduction information from pilot regions would be used to improve simulation results. Secondly, greater in-depth investigation should be undertaken to understand the real behavior of carbon markets. This would include surveys of the seven pilot areas, to assess carbon market designs and operational features, and progress in market development. Third, international cooperation is considered necessary to allow research to have an extensive global perspective. It is the intention of the State Information Center to continue to cooperate with Monash University/Centre of Policy Studies to improve the SIC inter-regional CGE model, and to cooperate with the Australian Government and the Australian National University to learn more about the first phase of the Australian carbon market as it develops.

Fourthly, strengthened by its capacity building cooperation programs and deeper policy simulation work, SIC should be able to undertake more research and analysis of cost effective carbon markets for Chinese central government agencies, aimed at improving policy and design formulation of China's national carbon ETS market and carbon cap and pricing policy, which is due to go into operation during the 13th Five Year Plan (2016-20).

Paper No. 4: Direct Carbon Emissions Entitlements and Indirect Emissions Entitlements: Recommendations to the Pilot City and Provinces' Carbon Markets in China

Dr. Li Jifeng and Mr. Zhang Yaxiong, Department of Economic Forecasting,

State Information Centre, Beijing

In the process of designing China's pilot regional carbon markets, an urgent task was to develop a mechanism that covers both direct emissions entitlement or rights (DEE, covering emissions generated from direct combustion of fossil fuel energy such as thermal power stations) and indirect emissions entitlement (IEE, covering emissions generated indirectly by electricity consumption) into the pilot carbon markets. In order to ensure that emission abatement incentives generated by carbon markets that are conducted by the demand side of the electricity market, a carbon market should not only cover both DEE and IEE, but also establish a trading system that allows trading in both. This research paper discusses this particular design, explains the principles underlying the designing process, and provides concrete recommendations to implement the scheme. Moreover, the paper also recommends complementary (regulatory) measures to reconcile the electricity and its related sectors, as these also hold the key to the success of integrated pilot carbon markets.

Taking into account China's current fixed electricity tariff regulating mechanism, especially the fact that electricity tariff adjustments are relatively insulated from the impact of carbon prices, including both direct and indirect emissions in pilot carbon trading markets and allocating IEE on the basis of indirect emissions generated from electricity usage, is compatible with the country's and especially pilot cities' circumstances (moreover, Beijing city is planning to introduce such a system covering both IEE and DEE in 2013, and other pilot cities are considering to follow this model). At the same time, this provided a better solution about how to establish and manage indirect emission entitlements. It is recommended that IEE be enacted on the basis of indirect emissions generated from electricity usage or consumption (in which large commercial, residential and public buildings, and transport, play an important role), in which carbon costs of indirect emissions can be passed downstream to end users.

Paper No. 5: An analysis of the economic impact of a carbon price under China's regulated electricity price system – Application of the China SICGE model

Dr. Li Jifeng, Wang Xin, and Zhang Yaxiong, Department of Economic Forecasting, State Information Centre, Beijing

China has shown a strong willingness to develop a low carbon economy through new economic policies, shifting from the traditional top-down regulatory measures of the previous two five year plans, towards the design and development of cost effective market-based carbon price solutions such as carbon emissions trading or the possible introduction of a carbon tax.

This paper explores the application of an RMB 100/tonne CO2 carbon price ($US 16/tonne) to SIC's China SICGE model, developed with the assistance of Monash University's Centre of Policy Studies. Using five scenarios and complementary policies, the short and long term impact on carbon emission reductions and on the nationwide economy were simulated. When simulating these policy scenarios, the existing market distortions in China were taken into consideration, especially the highly regulated electricity prices. A flexible mechanism was introduced into the SICGE model to make electricity prices exogenous or these prices were kept endogenous, with the aim to compare the economic impact of carbon pricing in three scenarios using different assumptions. In another two scenarios, the impact of different ways to re-distribute the carbon price revenue (from emission permit auctions in an ETS or from a carbon tax) were simulated.

The following main conclusions were drawn from the research paper's policy scenario simulations:

(1) Carbon pricing is an effective policy for China to reduce CO2 emission. Even with a fixed or stable electricity price, an RMB 100/tonne carbon price could lead to a CO2 emission reduction of 6.8% relative to the base scenario

(2) Keeping the electricity price stable when introducing a carbon price can be seen as a government subsidy to China's economic system. This would reduce the GDP loss from carbon pricing, but other policies would be needed to promote electricity efficiency and fossil fuel energy saving

3) When comparing the five policy assumption scenarios, and considering reductions in GDP loss while ensuring carbon emission reductions from carbon pricing, the fixed or stable electricity price scenarios are less efficient than those cases which were based on flexible electricity prices. These scenarios assume re-distribution of carbon price revenue in such as way as to promote economic system efficiency, such as reducing production taxes or reducing sales tax of consumption

4) Comparing the results of two simulation scenarios assessing options for the re-distribution of carbon price revenues, in the short-term, reducing sales taxes on consumption is shown as being superior. However, in the long-term, reducing production taxes will result in greater economic gains. It is recommended for policy consideration that the re-distribution of carbon price revenue system adopts an integrated approach to reduce both consumption and production taxes simultaneously

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Paper No. 6: Institutional analysis of introducing an emissions trading system to China's electric power industry

Dr. Teng Fei , Associate Professor Gu Alun, and Mr. Lu Zhiqiang
Institute of Energy, Environment and Economy, Tsinghua University, Beijing

This paper first analyses the carbon emission trends and projections in China's electricity sector, with a view of highlighting the importance of this sector in any future effective emissions trading scheme in China. The paper then reviews various ETS models worldwide, with a focus on how electricity generation and usage is handled in each of these different countries and regions. This is followed by an analysis of China's electricity institutional framework, and then by analyzing three options for introducing emissions pricing into the power sector and thereby integrating China's electricity sector into a future ETS. For each option, the advantages, disadvantages and institutional constraints are discussed. The paper concludes that any complete cost effective ETS would require a carbon price on both the supply side and the demand side. Further, regulatory and institutional reform of the electricity sector is urgently required, especially price liberalisation, and that low-carbon electric power policy should be developed as part of a whole sector liberalization policy package.

With 24.1% of the world's total carbon dioxide emissions in 2010 (IEA data), China has become the world's largest carbon emitter, and the second largest electric power producer. Electricity generation is the largest carbon dioxide emissions sector in China, accounting for 44% of total carbon emissions in 2010. In the coming decade, the scale of China's power industry will continue to expand significantly. Thus, the success of emissions reduction in the power sector will be crucial for reducing the government's targeted carbon emissions intensity of its GDP by 40-45% by 2020 from its 2005 level, and promoting its climate change mitigation goals. The power sector is therefore at the heart of China's climate change challenge.

As an internationally recognized major carbon emitting sector, electric power has been included in all international emissions trading systems, which are regarded internationally as the most effective market instrument to achieve least cost emissions abatement and significantly reduce carbon emissions. Given China's very large power sector, it is therefore vital for this sector to be included in China's carbon market, and that an effective emission trading scheme be established in China. However, the world's ETS experience is built on competitive power markets and cost based (cost pass through) pricing systems. In contrast, China's power industry is subject to a government fixed price system, and this sector is only at a very early stage of transition towards a market-based competitive mode. In this situation, the existing equal share power dispatch system and highly regulated pricing system in China has created obstacles for any introduction of emission trading.

Thus, to what extent the electricity sector will be included in China’s upcoming carbon market will have considerable impact on the design, implementation and performance of China’s ETS. Several domestic studies have confirmed that the emission reduction potential of the electricity industry is mainly in the supply side. However, in the current design in several pilot ETS schemes in China, which are planned to commence limited operation in 2013, only indirect emissions on the power consumption (demand) side are considered. Such designs are a compromise given the current state fixed pricing policy in the electricity sector, and as such, these will not have a substantive impact on the pilot and national long-term power investment and emission trends.

In this analysis, three options are identified for introducing emissions pricing in the power sector and integrating emission trading into the broader program of power sector institutional reform. These options differ in terms of policy intervention, prices, and the level of electricity supply and demand responses, but they recognize that for a carbon trading market to include the power sector and be effective, the existing highly regulated retail pricing system policy would need to be reformed and made flexible. This would have to involve the linking of retail electricity prices with power purchase costs that ensure a cost and price pass through further downstream activities.

To explore carbon abatement potential in the electricity sector, the most effective way under an ETS is to impose a price on both the supply side and the demand side, especially the supply side where the carbon intensity of a power generation unit is mainly determined by the electricity dispatch order. To reflect the emission cost of different generation units in the dispatching merit order, this can be achieved either through a top-down command and control regulation such as “energy saving dispatch” or “low carbon dispatch”, or though the combination of a competitive power market and carbon market model. The analysis concludes that the development of an efficient lower carbon power system in China is heavily constrained by the existing power industry institutional structure and state fixed retail price system, and that a lower carbon power policy could only be introduced as part of whole sector reform package aiming at further liberalisation of the electricity sector in China.

Paper No. 7: Increasing China’s coal-fired power generation efficiency – Impact on China’s carbon intensity and the broader economy to 2020

Mr. Shenghao Feng, Australian National University, and Dr. Yinhua Mai, Centre of Policy Studies, Monash University, Melbourne

The efficiency of China's coal-fired electricity generation has improved rapidly in the past decade. This improvement was achieved through the installation of more efficient large scale coal-fired electricity generation capacities and the forced closure of smaller-scale generation plants (2005-2011, 80.28 GW in capacity). Although the pace is slowing down, the trend is likely to continue, especially giving the Central Government's commitment to reduce the ratio of carbon emission to GDP (emissions intensity). In this study, the economic, financial, and environmental impact of China's coal-fired electricity efficiency improvements were analysed, and the most-likely and other scenarios of this efficiency improvement in future years were simulated.

The analyses showed that improved coal-fired electric plant efficiency led to higher employment in the short run and a higher capital stock in the long run relative to the baseline, which was the case without improvements in efficiency. This reinforced the direct positive impact of the improvement in efficiency on GDP. Although a higher GDP is a factor that dampens the emission-reduction effects of the improvement in efficiency, overall, the improvement in efficiency leads to a lower CO2 emission relative to the baseline. In the most-likely scenario, a continued improvement in efficiency over four years leads to an increase in real GDP of 0.15 per cent and a decrease in CO2 emission of 1.2 per cent in the long-run relative to the baseline. This policy instrument has the positive impacts on both economic growth and emission reduction.

The higher GDP and the GDP equivalent of the emission reduction relative to baseline form a future income stream – the gain from the investment made by choosing larger and more efficient power generation units. The net present value of this income stream calculated with a 5 per cent discount rate is estimated to be higher than the amount of investment required financing the improvement in efficiency.

Judging from China's policy of adopting more efficient technology and the technological potential of larger and more modern designed coal-fired power generation, improvement in coal-fired electricity generation efficiency is likely to continue to be one of the effective instruments for China to reduce CO2 emission, while maintaining a sustainable growth in the coming decade.

Concluding remarks and recommendations made by Professor Ross Garnaut, Melbourne University, Australia, at the NDRC-SIC Carbon Market Beijing International Workshop, January 31 2013 (*The design and development of cost-effective market mechanisms for carbon emissions reductions in China - Economic modelling and international experience)*

"In my concluding remarks, I hope to pick up a few impressions that I have had during the day, and make some suggestions for things that our friends might like to think about as they plan to take China forward.

I will raise a few issues that have come up in discussions and show how these could relate to a future research agenda. On the important issues that needs further work, first, a very specific thing. Philip Adams showed that for Australia, one of the costs of mitigation - and this is looking at the global situation - is that a fall in our export prices could lead to a deterioration in our terms of trade. This is due to other countries reducing emissions, and reducing demand for things that we export such as coal and natural gas. On the other side of the coin is that if the world engages in strong mitigation, Australia's export prices will fall and terms of trade will fall, but China's terms of trade will rise. Every fall in commodity prices (eg. coal and LNG) is a loss for Australia and a gain for China. And this could be very big. The global prices of China's imported commodities have been rising strongly in the last ten years because Chinese demand for oil, gas and coal, has been growing strongly. If the world has a strong mitigation effort, there will be slower growth in demand for these emissions intensive products, and prices could be much lower for China than it would be otherwise. This could be a big gain for China from the global mitigation effort.

In Australia, I have some challenge explaining to everyone that it is good for everyone and Australia to join in the global mitigation effort, because we could share in the benefits of solving the climate problem, but some people say that our terms of trade and export prices will fall. This is true. But for China it is the opposite. It helps China's argument. It might therefore be worth considering in the next stage of modelling for you to look at how big this gain might be for China. I think it may be very big.

I was very interested but was also a little bit concerned about some of the workshop discussions on the implementation of emissions trading at the provincial and city level in China. I would like to make a few points about that, and this would suggest a research agenda. First, I think we do have to be very careful about modelling on a province by province basis. The objective must be to introduce an effective national or nationwide mitigation. The pilot schemes are only a learning step towards building a national scheme.

But the effect of a national scheme will also be different in some important ways. It is therefore important to take this modelling further, and to a new stage where we have a strong focus on national results, whereas today at this workshop we have largely focussed on provincial and municipal results.

A very important question is how you allocate permits and how you allocate the value of permits. When you introduce an ETS, and if you set the cap at a level that is restrictive, and a price which is positive, then you are taxing the people. You are putting a new tax on the people. Then there is a question of who should get that tax revenue. If you give permits free to enterprises, you are simply taxing the ordinary people and giving all the revenue to enterprises. That is contrary to the spirit of the 12th Five Year Plan, where there is a very strong emphasis on greater equity and on raising of the standard of living of ordinary people. If you make companies pay for a carbon price or permit, these companies will charge higher prices (this is the way the market economy works, unless there are price controls) and they will pass the price through.

Enterprises will get richer. People will have to pay the higher price, and that will make people poorer. This will lead to falling consumption while the profits of enterprises will rise. This violates the 12th Five Year Plan's objectives of increasing the consumption of the people.

Because you are imposing a tax and giving the revenue over to enterprises, you are reducing some of the country's taxing capacity. That means you are increasing the cost of public financing as every tax has a deadweight cost. It should be the objective of the nation to get tax revenue in the lowest cost way and easiest way possible. If the government re-distributes the revenue to services and welfare, and to reduce income and business taxes, you then have the capacity to reduce other forms of taxation. Economists have a very strong view that it is best to raise the revenue and reduce other taxes, this will reduce the cost of collecting other forms of taxation, and this will lead to a more equitable and more efficient economy.

In Europe, the European Commission gave permits away for free, and the people of Europe became poorer as prices of energy rose. People talked about "energy poverty" because electricity prices and petrol prices went up, and people were not compensated. The ETS became unpopular amongst the people for that reason. In Australia, we collected the majority of revenue through the auctioning of permits, and collected the revenue, and then we gave away this revenue as compensation, including through tax cuts. The people still have an incentive to use less electricity as the price will go up, but the people won't get poorer, as they received tax cuts, other compensation and social security.

I would suggest that in the next stage of research analysis, there should be some detailed analysis on income distribution effects and on different ways of handling the revenue side. Until this work is done, and until that you are satisfied that you have the right system for allocating permits (and I would recommend that you allocate most through auctioning of the permits), I would suggest you keep an open mind about a carbon tax, because a carbon tax does not have all of these other problems..

The majority of very good US economists (starting with Cooper in Harvard, and Nordhaus in Yale) are against an ETS, and in favour of a carbon tax, because they think an ETS will work as in Europe where the value of permits will be given away free to enterprises. Some people like Nordhaus believe that that an ETS has some advantages if one actually auctions the revenue. This is a very important research question to keep on the research agenda.

Another issue that came up in discussion (Dr. Li Jifeng's electricity paper) is the importance of having flexibility in electricity pricing if the ETS or carbon pricing system is to work effectively. Some of the advantages of the ETS come on the demand side, reducing demand for emissions intensive goods and services, and some come on the supply sides. You don't get any of the benefits on the demand side unless you have price flexibility. I know that is a hard reform. But this is a really important reform, not only for economic efficiency. An ETS or carbon tax will work much better if one has a flexible electricity pricing system. So I recommend that you look at that closely in your further research.

Several of the papers today make very good use of General Equilibrium (GE) modelling. Here I really recommend that you keep doing more of this type of work because it is the GE modelling that allows you to look beyond the first round affects. First round affects are only a small part of the story. If you had a high enough carbon price to affect behaviour quite a lot, then one of the things that would change (and this comes out in CGE modelling) are changes is the exchange rate. Export industries which are relatively low in carbon intensity actually become more competitive. You don't pick this up unless you have GE modelling. It is therefore worth continuing to explore the 2nd and 3rd round effects of GE modelling.

Business people will never look at 2nd and 3rd round affects; they will only look at the first round affect, and then they will argue for compensation. If one takes into account the general equilibrium effect, costs of factors of production, and the real exchange rate, companies are very likely to receive a benefit. So there is value in further extending this type of GE modelling research work.

In the context of looking at the income distribution effects of an ETS or carbon tax, you should also specifically research carbon pricing as a form of taxation, and look at whether it is more or less as efficient as other form of taxation. American economists refer to its efficiency, and argue that a carbon tax is a very efficient form of taxation, and that the costs of this form of tax are less than other types. Moreover, if one used carbon tax revenue to cut income taxes or cut business taxes, then the overall efficiency effects will be positive. So I suggest that this also becomes an important area of your research.

Finally on the research agenda, there is room for a lot of detailed studies on what is actually happening to reduce emissions once incentives are introduced. One nice example is in Dr. Yinhua Mai's paper on the electricity sector. A CGE model is built up using a lot of production functions; these change over time. Costs of mitigation will depend over time on how the production functions will change over time. Detailed studies are needed about what is happening with the production functions for other form of energy, such as wind, solar, nuclear, hydroelectricity and various forms of transport. These are the building blocks that provide the detail for CGE modelling that Prof Phil Adams talked about earlier.

I think we will find out very important things for the world from China, as what is happening in China in renewable and larger scale technologies in many cases are leading the world. We can all learn from that.

Let me conclude again by congratulating you on all the excellent work you have done, and I encourage you to take this work further."

Recommendations for follow-up carbon market research activities and new project proposals

The NDRC-SIC Beijing International Workshop held in China on January 31 2013 provided an opportunity to discuss and assemble a variety of experts' recommendations for follow-up carbon pricing and market research activities, deeper research work, analysis around further policy questions, and suggestions for complementary project proposals. Many of the research papers also provided research recommendations in their particular field. Prof Ross Garnaut, in his concluding workshop remarks (see immediately above), also added important suggestions for the next stage of project research analysis.

As a result of the research papers and discussions and recommendations at the Beijing Workshop, the NDRC State Information Centre prepared in March 2013 a draft summary proposal for a new project, entitled "*China's carbon emissions reductions - Modelling economic and fiscal effects and analysing effective policy design*". The new project would build on the current successful project, and would broaden engagement with other agencies and institutions. It would focus on research into the cost effectiveness and economic impact of an ETS, and include fiscal implications. A carbon/environment tax would be addressed for comparative analytical purposes. The summary proposal has two main components:

(i) Quantitative research capacity building & modelling analysis
(ii) Policy application and qualitative research for policy design analysis, including the design of carbon price and ETS mechanisms, revenue re-distribution systems and options, analysis of marginal abatement costs of emissions, and electricity sector pricing and institutional reform

The following is a summary of the collective recommendations (in some cases these are in the form of direct statements) made in the papers and at the Beijing Workshop. These have the potential to form a follow-up research agenda, and inform the contents of a new project proposal document for future funding and contractual purposes.

1. Prof Ross Garnaut, Melbourne University: Comparative research into the impact of a simple carbon tax's revenue on low and middle income households and low emission activity innovation, and the impact of an ETS' revenue with free permits

Statement, 8 February 2013: *"In the course of the workshop meeting I had become more aware of the risks for China of going down an ETS route within the political economy constraints that it had, and that in my concluding remarks I had suggested keeping open the option of a simple carbon tax and doing more research related to the choice of ETS and tax for carbon pricing*".

An ideal research agenda would include the following:

(a) Impact of a simple carbon tax's revenue re-distribution aimed at developing a more equitable and more efficient economy, with revenue directed towards:
   (i) Low and middle income households;
   (ii) Reduced business or corporate taxation (re-structure of business or corporate taxation); and
   (iii) Low emission activity innovation (incentives and subsidies for renewable energy and energy efficiency)

(b) Impact of an ETS with free permits on revenue re-distribution to:
   (i) Low and middle income households;
   (ii) Reduced business or corporate taxation (re-structure of business or corporate taxation); and
   (iii) Low emission activity innovation (incentives and subsidies for renewable energy and energy efficiency)

(c) In-depth research into carbon pricing as a form of efficient taxation, and analysis of the re-distribution effects of carbon pricing revenue

(d) In-depth research into carbon emissions reductions as a result of the introduction of energy efficiency and renewable incentives, and research into the production functions of coal-fired power stations and other forms of energy production functions

2. Mr. Sun Zhen, Deputy Director General/General Counsel, NDRC Department of Climate Change: The need for further research into a new carbon tax in China, and its features and impact

(a) Provide further independent analysis (beyond work undertaken by the Ministry of Finance's Institute of Fiscal Science) on the priority adoption of a long term carbon tax (or "climate change tax") on carbon pollution, how it can be integrated into the energy and resources tax system and a total tax reform and restructure program under a legislative framework;

(b) Analysis of the impact of variable carbon price rates (and coverage) on national emissions reductions, fiscal conditions (revenue, and re-distribution in support of households, renewable energy, energy efficiency incentives, and other more efficient tax reductions), and long term economic growth

3. Prof Zhang Xiliang, Director, Institute of Energy, Economics and Environment, Tsinghua University, Beijing

(a) Modelling and policy analysis at the national and provincial (regional) level of the lowest carbon emission (intensity) mitigation costs, to enhance market-based cost-effective policy measures, and to guide improved government provincial emissions reduction targets and policy settings

(b) An analysis of carbon price options and the most cost effective (economy-wide impact) method of revenue re-distribution in pursuit of low carbon economic objectives.

4. Mr. Zhang Yaxiong, Deputy Director General, Economic Forecasting Department, State Information Center, Beijing

The State Information Center provided the following list of objectives and further research activities on the establishment of an Emissions Trading Scheme, its cost effectiveness, and economic impact, for a new project proposal, or Phase 2 of the current project. It was presented in a two part framework: the first addressed largely quantitative research and assessment work; the second addressed more qualitative research and analytical issues.

The proposed title of the new project proposal is “China's carbon emissions reductions - Modelling economic and fiscal effects and analysing effective policy design”

Component (A): Deeper model building and modeling capacity building: Quantitative research capacity building and analysis (China SICGE and CGE dynamic inter-regional model improvement and policy simulation)

(1) Improvement of the SIC carbon emission module – using the China SICGE model and the SICGE-R-CO2 model
(2) Improvement of the tax/revenue and income re-distribution module, using the China SICGE model
(3) Production functions in key emission intensity sectors, using the China SICGE model and the SICGE-R-CO2 model
(4) Disaggregation of electricity generation and other energy generation sectors, using the China SICGE model and the SICGE-R-CO2 model
(5) Improvement of the newly-developed SICGE-R-CO2 bottom up inter-regional model developed under the Phase 1 (current) project, with a carbon dioxide emissions permit trading module, based on Monash University/CoPS “TERM” dynamic inter-regional model

This work would need to be undertaken in collaboration with Monash University/Centre of Policy Studies. This would involve development of a master database for the bottom up dynamic regional model and aggregation program, calibration of initial capital stock, investment growth, and industry sector growth in the baseline construction for the inter-regional model. This will give SIC the capacity to use the more advanced regional dynamic model with different regional aggregations, and assist SIC about how to design simulations to address the listed policy questions under Component (B) below, and how to draw insightful policy conclusions from the simulation results.

More detailed simulations would be developed in line with progress achieved under the Phase 2 proposed project.

Component (B) Policy application and qualitative research for policy design analysis: Design of the carbon price and ETS mechanism, revenue distribution system, and analysis of the marginal abatement cost of emissions and electricity system pricing reform

This research would include, as appropriate, policy simulation work based on the improved models and modeling undertaken under Component (A)'s quantitative work. The carbon/environment tax will be addressed here, but only for comparative analytical purposes.

(1) National level ETS design (carbon emissions cap, emissions and enterprise coverage, permit allocation, carbon pricing, etc) and economy-wide impact study. Policy application research would include an associated study for comparative purposes of the design, implementation and impact of a carbon/environment tax in China (see (3) below).
(2) Longer term research study of carbon emission reduction costs (including a marginal abatement cost (MAC) study), and the necessary carbon price level at different stages of China's economic development
(3) Comparative analysis of the design, imposition and impact (including fiscal implications) of a carbon tax instead of an ETS
(4) Carbon price revenue re-distribution fiscal options, to fund renewable subsidies and energy efficiency, company and income tax reductions, and household compensation or welfare (working with the NDRC Department of Fiscal and Financial Affairs, the Ministry of Finance/Institute of Fiscal Sciences, and CASS)
(5) Electricity sector reform economic analysis: Focus would be on policy-relevant economic studies in the electricity sector, such as electricity price reform, abatement cost of power generation, etc, taking into consideration distortions in the electricity market and analysis of the distortions in the power market, building on and expanding the research work undertaken for the current SIC project by (Dr. Teng Fei and Tsinghua University colleagues in the Institute of Energy, Economics and Environment would be involved in this study)
(6) Evaluation of the strategy and impact (price, cost etc) of moving ETS carbon pricing from the pilot stage to a nationwide emissions trading scheme, and the impact on and implications at the regional/provincial level

5. Dr. Liu Yu, Economic Forecasting Department, State Information Center, Beijing

(a) Further improve the SIC bottom-up static inter-regional climate change CGE model (SICGE-R-CO2), developed with the assistance of Monash University (CoPS) on the basis of its TERM model, by introducing more detailed data, including experience from the seven ETS pilots;

(b) Use the model to undertake more in-depth simulation of carbon emissions permit trading, determine optimum industry coverage, improve the national ETS design, acquire capacity to understand other foreign (Australian) carbon markets and model global trading;

(c) Undertake in-depth modelling and analysis of carbon trading revenue and its most effective re-distribution; and

(d) Working in close collaboration with the central government (NDRC), provide more in-depth policy-relevant analysis and recommendations for the design and development of the national carbon market

6. Dr. Frank Jotzo, Australian National University, Crawford School of Public Policy, Centre for Climate Economics and Policy: Electricity sector study - Optimal electricity dispatch with a carbon price

This suggestion for a more detailed electricity sector research would require taking forward the project research already undertaken by Tsinghua University’s Associate Professor Teng Fei (*Institutional analysis of introducing an emissions trading system to China’s power industry*). It is suggested that the research study, “Optimal electricity dispatch with a CO2 price”, would need to involve the following tasks:

(a) Estimating the optimal electricity dispatch mix with a CO2 price (at different price levels?)
(b) Estimating CO2 emissions levels
(c) Estimating operating costs including loss in profits of smaller/less efficient plants
(d) Comparing these scenarios to the existing mandated dispatch
(e) Discussing how the change could be made institutionally.

This analysis could also build on the October 2012 release of the IEA/ERI research paper “Policy options for low carbon power generation in China: Designing an emissions trading system for China’s electricity sector” (p.34-35). Implementation of this research would require an engineering dispatch model, which may be made available from China’s State Grid Corporation.

7. Dr. Frank Jotzo, Australian National University, Crawford School of Public Policy, Centre for Climate Economics and Policy: Emissions pricing research recommendations

In-depth qualitative and quantitative research will be needed over the coming years. The payoffs from applied research in this area could be very large. If China succeeds in establishing an effective, efficient and robust emissions pricing scheme, this could have a strong demonstration effect for the world, and encourage other countries to emulate the experience

(a) Emissions trading: Abatement action

Quantitative research is needed on the amount and cost of abatement likely to be achieved from different sectors. This can be done using top-down computable general equilibrium models, and bottom-up engineering-economic models. Useful research questions for modelling applications include:

- What is the relative contribution of different sectors of the economy to overall abatement, at different carbon price levels – in absolute and percentage terms?
- What is the relative importance of different aspects of abatement action, eg fuel switching, energy efficiency improvements, and changes in the composition of supply and demand for goods and services as a result of a carbon price?
- How does the cost of achieving a given amount of overall abatement depend on the extent of coverage; what is the cost advantage of broader coverage?

Further quantitative research is indicated on the likely magnitude of transaction costs and administrative costs in various sectors, for different thresholds for inclusion in ETS, and for the different modes of coverage. These aspects of cost are usually not included in the modelling of mitigation, but need to be considered in deciding optimal coverage.

This research needs to be complemented with qualitative research on the institutional feasibility of coverage through different modes of coverage in different sectors, to help decide what extent of coverage is feasible in practice. Experiences in the pilot schemes can be a valuable source of information in making coverage decisions for a national scheme. Research could investigate the actions taken, and transaction costs incurred, of companies of different sizes and in different industries.

(b) Emissions trading: Setting an emissions cap and trajectory

Quantitative analysis and modelling will be needed on various aspects of likely future emissions trajectories and mitigation responses in order to inform the setting of ETS caps and rules, such as for banking and borrowing.

Research questions would include:

- What is the likely range of emissions growth scenarios of emissions outside of the ETS, given the policies that apply to these emissions sources (this determines the allowable emissions under the cap for a given overall target)
- How does the extent of coverage of the ETS affect emissions growth outside of the ETS
- How does the underlying growth rate in emissions, inside and outside of the ETS, change in response to slower or faster GDP growth
- What is the likely trajectory of emissions growth inside the ETS, in response to an emissions price (this in part determines banking and borrowing).

CGE modelling, and partial sector specific models and projections – in particular for the energy sector – and regression-based analysis can all be useful in conducting such analysis. The analysis will generally need to be conducted from a stochastic viewpoint, identifying ranges and likelihoods rather than just expected values.

(c) Emissions trading: Price management and market stabilisation

Quantitative modelling is needed of the effect that various levels of minimum and maximum prices under a Chinese ETS may have on emissions levels. This is in order to be able to inform decisions about permit price ranges that would enable China's emissions target range of a 40 to 45% reduction in emissions intensity to be met. Research methods are closely related to those for modelling of emissions caps, discussed in the project research paper. They comprise CGE modelling, partial sector specific models and projections, and regression-based analysis.

In addition, surveys of experts and potential market participants ahead of the introduction of pilot schemes or a national scheme could be useful in gauging market expectations.

(d) Emissions trading: Permit allocation and revenue

To inform allocation decisions, firstly qualitative analysis is needed of the in-principle issues facing different industries in China – for example to what extent is it expected that there will be price pass-through to end users that will allow emitters to recoup carbon costs; what if any is the risk of inefficient relocation of industry (carbon leakage); and where assistance payments are necessary, what design will achieve efficient outcomes.

Secondly, detailed quantitative modelling is needed to understand the likely nature and magnitudes of distributional impacts on different industries and different types of households.

The modelling undertaken by the Australian Treasury, consisting of a detailed domestic CGE model coupled with household expenditure models, can be a guide to such a modelling effort. In addition, modelling using sector specific partial equilibrium models will be useful, in particular for the electricity sector.

International experience suggests that assistance arrangements including permit allocation could become the area that is most hotly contested in domestic policy formulation. Reliable analysis is needed to facilitate good policy design.

(e) Emissions trading: Permit allocation and revenue

To inform policy decisions about carbon pricing in China’s power sector, quantitative analysis is needed of system-wide responses to different modes of carbon prices and related changes in regulations.

For such modelling to be of maximum use, it will need to include a reasonable representation of regulatory and pricing policies in China’s power sector. This in turn will require a model that goes well beyond the extent of detail that is represented in standard CGE models. Nevertheless, CGE analysis will be useful to gauge economic flow-on effects of changes in the power sector, including effects that emanate from changes in power prices and electricity sector investments.

In addition to the quantitative modelling, qualitative work is needed to thoroughly understand the effects that various possibly changes in power pricing and regulatory structures will have, by themselves and in combination with various forms of carbon pricing.

Part 1: Keynote Paper

National Contributions to the global mitigation effort: Issues for Australia and China

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National Contributions to the Global Mitigation Effort: Issues for Australia and China

As the Chinese National Development and Reform Commission (NDRC) observes in its first survey of Chinese climate change policies in November 2012, "China is one of the countries most vulnerable to the adverse impact of climate change" (NDRC, 2012).

It shares that reality with Australia, for which the extreme heat and bushfires in early 2013 join the increasingly common extreme weather events that carry a climate change footprint.

We are two of the most vulnerable countries, but we share vulnerability with the whole of humanity. Extreme weather events have become more common and severe on all continents. Some of the manifestations of more common and severe extreme weather events, for example as higher global food prices, have been felt everywhere.

The association of extreme weather events with climate change is complicated and can be confusing, because natural climate variability would anyway have introduced damaging extreme weather events from time to time. We can characterise the way that global warming has affected weather in probabilistic terms by thinking of outcomes as being the result of the throwing of a standard dice with six faces. Natural variability would sometimes have generated a one or a six from the roll of the dice, and the average would have settled around three and a half. The early stages of global warming—the increase of a bit below one degree Celsius in average temperatures so far since the concentrations of greenhouse gases began to build up strongly in the middle of last century—can be represented as having removed the one and replaced it with a seven. In the absence of effective global mitigation, we will replace the two by an eight, and then the three by a nine, with other replacements to follow. When the nine has replaced three, the average outcome from the throw of the dice will become six and a half. What once were one in two hundred throw events—an average of six over three throws--will have become average occurrences. We may still throw a four from time to time; but we will now sometimes see a nine;

we will never again see a one; and the average outcome will be higher than the most extreme at the beginning.

This is the probabilistic sense in which climate scientists should be understood when they say that no particular extreme event can be said to be caused by global warming, but that extreme events will happen more often and the worst will be more extreme than before.

Climate change takes us into unknown territory for human civilisation.

Human civilisation emerged along the Yellow River and other great river valleys of Eurasia and North Africa over these past twelve thousand years of equable temperatures which scientists have called the Holocene. During this long period, average temperatures varied within a relatively narrow range—a range whose upper limits we are now breaching.

Through the Holocene, human civilisation grew through the long accumulation of experience in governing populous states, the long accumulation of knowledge of many kinds, and much sharing of experience through friendly trade and deadly conquest. Sometimes the deadly conquest and trade came together: the Mongol conquerors destroyed state structures and disrupted ordinary life across much of Eurasia. They also brought the experience of the Persian state to China and facilitated the long distance trade that took the technological genius of Song China to Europe and provided building blocks for the industrial revolution.

Many people in many states contributed to the knowledge and institutional arrangements that lay the foundations for the emergence in Britain a quarter of a millennium ago of what we now recognise as modern economic growth.

Modern economic growth eventually delivered great bounties to people who embraced it. The bounties came with cost, disruption and pain. The cost and disruption caused hitherto successful societies like old China to be cautious and slow in embracing it. Its uneven distribution across humanity conferred great power upon its early hosts, giving rise to the phenomenon of Imperialism with its manifold iniquities. But in the end, modern economic growth delivered higher living standards, more secure food and shelter, healthier and longer lives, more knowledge and experience of life for people who joined it. Modern economic growth came to be wanted by people all over the world.

Over the past quarter century humanity became aware that modern economic growth came with costs that had not been recognised in earlier times. There were incidental or external costs, which had to be managed and contained if they were not to destroy the natural conditions that nurtured the emergence of human civilisation and modern economic growth. One of these costs, the most urgent and dangerous, is human-induced climate change.

Modern economic growth draws on huge amounts of energy. The cheapest and most convenient way of securing much of the necessary energy was by burning fossil fuels. Fossil fuel combustion returned to the atmosphere some of the carbon dioxide that had once made the earth too hot for human life. The natural capture of carbon dioxide from the atmosphere through photosynthesis and its natural sequestration in the earth over hundreds of millions if not billions of years established the climatic conditions under which human civilisation emerged and prospered.

The accumulation of carbon dioxide in the atmosphere raises temperatures on earth. Humans are now creating the climate in which we must make our lives. Humanity has entered the anthropocene.

The brilliant species of which we are members has come an amazing distance in building civilisation over these last twelve thousand and especially two hundred and fifty years. The question is whether humanity can manage the external costs of its success. Can humanity manage the anthropocene?

People everywhere want the benefits of modern economic growth, built on high levels of energy use. When I discussed these matters with Chairman Deng Xiaoping over a quarter of a century ago, he said that by the middle of the twenty first century the people of China would enjoy the living standards of a middle income country, and that he hoped that they would then be satisfied. These were wise thoughts; but people in China like people everywhere are not easily satisfied, and want the best and the most that available technology and resources can give to them.

People everywhere want the living standards that are currently enjoyed by residents of the high-income economies. But if we seek to achieve those living standards by using energy in the quantities and forms that underpinned modern growth in the economies that are now developed, we will change the earth’s climate in ways that are unlikely to be compatible with stable states and sustainable prosperity.

The idea that the finite nature of fossil fuel resources would limit economic growth is an old one. It was a discussed a long time ago by some of the biggest names in economics and the other social sciences. Jevons discussed the coal-imposed limits to British growth one and a half centuries ago (Jevons, 1865). Weber saw the wellsprings of capitalist economic growth running dry when “the last ton of fossilized coal is burnt” (Weber, 1905). In his classic ‘Conditions of Economic Progress’ which pioneered modern analysis of economic growth, Australian economist Colin Clark opined that we can calculate the likely amount of fossil fuel from the carbon that was once in the atmosphere. “However, we must not set out to burn them up too fast, even if we do find them, at any rate not faster than the rate at which carbon dioxide can be stored by photosynthesis”. But, Clark added, economic growth itself need not be limited by the availability of fossil fuels: “there is an abundance of solar energy falling on the earth if we know how to tap it” (Clark, 1940).

Clark's view that economic growth can be sustained by shifting from fossil to renewable energy has been confirmed by contemporary economic analysis. Elaborate quantitative studies by Stern (2007) for the world as a whole and Garnaut (2008) for Australia showed that carbon emissions could be reduced to the low levels necessary to stabilise global temperatures at moderate costs—costs that would slightly slow the growth in living standards in the early decades, and be much lower than the costs of unmitigated climate change after that.

The question whether we can manage the anthropocene will be answered, yes or no, for humanity as a whole. It will not be yes for people living within some states and no for others. If rising temperatures and changing climate in the anthropocene corrode the physical foundations for human civilisation, there will be no pockets of respite in Hohhot or Hobart, Jinan or Geelong, Beijing or Binalong, Xian or Xi Ao.

Stern called the absence of constraints on emissions of climate-changing gases the greatest market failure the world has ever known (Stern, 2007). The challenge is to have all humans take into account the external effects on global climate of all of the decisions that they take in pursuit of economic growth. Collective action is required through all of humanity.

No state governs the whole of humanity to define the collective action that is required and to enforce rules that correct the market failure. Humanity can manage the anthropocene only if it can build mechanisms within which global collective action can be effective.

The Emergence of a Global Climate Change Regime

China and Australia have been active participants in the international community's work to build a basis for international cooperation on climate change since the beginning at Rio de Janeiro, two decades ago. In 1992, there seemed to be lots of time, and the problem seemed to be overwhelmingly that of excessive emissions from the developed countries.

That impression guided the meeting of the United Nations Framework Convention on Climate Change in 1997 and the resulting Kyoto Protocol. By then there had been considerable progress in sharing perspectives within a uniquely ambitious and successful effort in international scientific cooperation, through the Intergovernmental Panel on Climate Change. Understandings were reached on which gases would be covered by efforts to reduce emissions, and on how they should be measured. An agreement was reached that all developed countries would accept constraints on emissions, and that there would be penalties for breaches of commitments. There would be opportunities to reduce the costs of mitigation through Joint Implementation among developed countries (where countries that were falling below their emissions reduction targets would be able to buy entitlements from countries that were reducing emissions more than was required by their targets). There would be opportunities for reducing the costs of mitigation in developed countries through a Clean Development Mechanism (CDM), which would certify carbon reduction "offsets" generated in developing countries for sale to developed countries.

Developing countries undertook to make efforts to reduce emissions; developed countries to contribute funding to these efforts and also to climate change adaptation in developing countries.

The Kyoto arrangements were damaged when the United States Congress refused to ratify the agreement to which the United States Government was a party. The George W. Bush Government elected in 2000 announced that it would not seek ratification for the agreement. The Australian Government followed the United States lead and continued to do so until policy was reversed in 2007. But both Australia and the United States remained parties to international discussions. Progress was made on some issues in conferences of the United Nations Framework Convention on Climate Change (UNFCCC) in Bali (2007), Copenhagen (2009), Cancun (2010), Durban (2011) and Doha (2012), including on a global objective of holding the human-induced increase in temperatures to two degrees Celsius.

These early efforts in collective action on climate change contained elements of success and failure. It is important to preserve the success (the scientific cooperation, the shared objective, the agreements on how to measure and later to account for and verify emissions, the mechanisms for international trade in entitlements and for transfers of financial resources to developing countries) while correcting the causes of failure.

Time has passed and times have changed.

We no longer have time: the concentrations of greenhouse gases are already approaching levels that are likely over time to generate two degrees increase in average temperatures. Emissions have grown more rapidly since the turn of the century than the most widely used scenarios developed in the 1990s had suggested, largely because growth was stronger and more energy-intensive and energy more emissions-intensive than had been anticipated (Garnaut et al., 2009).

If temperature increases are going to be kept to two degrees, there must be an early and large reduction in global emissions trajectories. Global emissions must be reduced by half or more by mid-century by putting them on a downward path now. Delays in turning down the trajectories will require an earlier end point for the emissions reductions and a more rapid rate of decline. The practical requirement that all parts of humanity see the distribution of the global mitigation effort as being fair points to movement towards similar per capita emissions entitlements in all countries—at levels more than 90 percent lower than those present today in developed countries and more than 50 percent lower than today in China.

In contrast to the world up to the Rio de Janeiro summit, emissions growth in the twenty first century was overwhelmingly concentrated in developing countries. My own calculations on “business as usual” emissions for the Climate Change Review Update (Garnaut, 2011a, 2011b) suggested that in the absence of policy action to change established trends, developing countries would account for the whole of the increase in global emissions from 2005 to 2030; developed country emissions as a whole were expected to remain steady between 2005 and 2030. In the absence of policy action, China would account for 41 percent of global emissions in 2030 and developing countries 70 percent. Whatever weight were given to the requirements of historical responsibility and justice, effective global mitigation would require major and early reductions from business as usual emissions in China and other developing countries.

The Kyoto arrangements had envisaged a comprehensive “top-down” agreement in which responsibility for constraining emissions would be allocated across countries and enforced internationally. This ideal would provide a firm basis for international trade in entitlements, to allow reductions in emissions to occur where they could be achieved at lowest cost. Such an agreement would provide each country with assurance that others were contributing their fair shares of the global effort, so that its own emissions reductions would be part of an effective global effort. It would provide each country with assurance that other countries’ emissions-intensive industries were gaining no competitive advantage in international markets against its own as a result of differences in mitigation effort.

The international community has learned slowly and painfully that such an agreement is not within reach for the foreseeable future. This reality came within view at Copenhagen in 2009, and crystallised in Cancun in 2010. It was not possible because the major powers, first of all the United States but also China, were willing to bind themselves domestically to strong mitigation outcomes, but unwilling to enter international agreements to the same end. It was not possible because there were no effective sanctions against breaches of commitments—as demonstrated by Canada walking away without penalty from its Kyoto Protocol pledges.

Subsequent developments raise a question about whether a comprehensive “top-down” agreement is even desirable. In anticipation of a legally binding agreement, Governments settle into negotiating mode and seek to minimise commitments. By contrast, when considering a domestic commitment, Governments are prepared to look more openly at the realistic boundaries of action and to go further in defining mitigation targets.

A different approach to setting national targets began to emerge at Copenhagen, took firm shape at Cancun and was elaborated in subsequent UNFCCC meetings in Durban and Doha. The new approach carries some important features over from the early international discussions. The scientific cooperation remains centrally important to the collective effort. The two degree objective, mechanisms for measurement and verification of emissions, and instruments for international trade in entitlements have been developed or strengthened. Ideas about mechanisms for transferring resources for mitigation and adaptation from developed to developing countries have been given substantive shape (although still little money). It must be said that additional steps need to be taken on verification of emissions: while a case can be made for developing country mitigation targets to be expressed in different ways from developed country targets (intensity rather than absolute reductions), there is no case for differentiation in measurement and verification.

The big departure from the old regime is in the setting of country targets for constraining emissions. It has been accepted that substantial developing countries will make commitments to constrain emissions, in the form of reductions in emissions intensity or “business as usual” emissions. (Intensity targets are strongly preferred to business as usual, as they are capable of objective and unambiguous calculation). It is accepted if only by default that these and developed country commitments to absolute reductions in emissions are voluntary and represent serious domestic undertakings and are not binding under international law. The voluntary targets are set domestically rather than within a comprehensive international agreement. The pressures to make them ambitious come from domestic politics and review and commentary from other countries—a process that is known as ”pledge and review”.

The new process can be described as “concerted unilateral mitigation”.

It is a feature of the Kyoto arrangements carried over into the concerted unilateral mitigation regime that each country is free to use whatever instruments it chooses in meeting its targets. It is free to acquit its commitments through the purchase of international abatement to the extent that it chooses, or not at all. It is free to introduce carbon pricing in the form of an emissions trading system or a carbon tax or not at all. Whether or not it places a price on carbon, it can choose to regulate emissions-intensive activities and subsidise low-emissions substitutes to the extent that it chooses. International comparisons of mitigation effort are made in terms of the outcomes in reductions in emissions below defined baselines, and not in terms of how the emissions reductions are achieved.

For concerted unilateral mitigation to be effective, one major gap in the international regime needs to be filled. The regime needs some framework for guiding assessments of the level of mitigation in each country that amounts to a fair share of an international effort to achieve the agreed global effort. It would be useful and probably necessary for heads of governments committed to strong global mitigation outcomes to appoint an expert group to develop such a framework for allocating the global effort among countries. Within the context of concerted unilateral mitigation, each country would be free to accept or reject guidance provided by such a framework. The framework would become a focus of international review of each country’s effort, and evolve over time in response to discussion and experience.

The Durban conference of the UNFCCC in late 2011 agreed to launch “a process to develop a protocol, another legal instrument or an agreed outcome with legal force”. The process, legal instrument or agreed outcome would be settled by 2015 and come into effect in 2020. Developed and developing countries would all accept obligations, although the form of those obligations could vary across countries.

The Durban decision was sometimes interpreted as a commitment again to seek a binding, tops down agreement, although the words allow other interpretations. At least there is no suggestion that we should return to seeking comprehensive agreement on the allocation of the required global mitigation effort across countries.

While there would be advantages in an internationally binding agreement if it were possible to achieve one without reducing mitigation ambition, the practical barriers to a good binding agreement remain as strong as they were at Copenhagen. It is important that we do not allow the search for excellent form to distract the international community from grasping immediate prospects for excellent substance.

To conclude the discussion of the evolution of the global climate change regime, we should acknowledge that trade in emissions entitlements has struck some large practical problems. Within the European emissions trading system, the many regulatory and fiscal interventions are forcing much larger reductions in emissions than carbon pricing. These together with slow growth in economic activity and the realisation of unexpected opportunities for low-cost abatement have caused permit prices to fall to levels that are well below the economic cost of emissions and the value of abatement. The low prices raise questions about the effectiveness of the emissions trading system. Although controlled in quantum, use of offsets at very low prices from the Clean Development Mechanism (CDM) has pushed prices even lower. Low European and CDM prices would, if uncorrected, introduce low prices into other emissions trading systems with which Europe is linked, notably Australia from 2015. Already New Zealand’s emissions trading scheme has prices close to zero through allowing unlimited access to credits from the Clean Development Mechanism.

It is understood by economists that broadly based carbon pricing achieves more carbon emissions reduction at similar cost, or similar abatement at lower cost, than large numbers of separate regulatory and fiscal interventions. Considerable emissions reductions have been achieved in recent years in many countries through regulatory and differentiated fiscal interventions. However, the cost advantages of general carbon pricing become more important as mitigation targets become more ambitious, and are likely to be essential to achieving the deep reductions in emissions that will be necessary to achieve the agreed global objective. The contemporary problems of uneconomically low prices in domestic and international trading schemes can therefore be seen as a threat to achievement of long term global mitigation goals. A tightening of emissions reduction targets is necessary to restore prices that relate appropriately to the cost and value of abatement in a world that is meeting its emissions reduction targets.

The Clean Development Mechanism (CDM) has emerged as the most important locus for international trade in carbon units, and for a number of years contributed substantially to incentives for investment in emissions reduction in developing countries. The NDRC has recently reported that to August 2012, Chinese certified emissions reduction under the CDM had reached 730 million tonnes per annum (NDRC, 2012), a bit over half of the global total.

As analysed in the recent report of an independent review panel, the CDM is experiencing chronic oversupply of abatement units. Prices have fallen to levels that barely cover transaction costs. With recent and prospective reforms, the CDM is a legitimate offset mechanism with a potentially valuable place in a global system of climate change mitigation (CDM Policy

Dialogue, 2012). The review panel concluded that a major tightening of emissions reduction targets and widening of access on the demand side would be necessary to correct the chronic oversupply. I would suggest as well a tightening of access on the abatement supply side, with only least developed countries having unconditional access. Other developing countries would have access if they accepted domestically binding emissions constraints and were living within those constraints without double counting of abatement for which CDM credits had been awarded. If this approach were adopted by the international community, international mechanisms would need to be developed (perhaps through the established arrangements for Joint Implementation) to monitor double counting of emissions.

The Cancun Pledges

Within the framework of concerted unilateral mitigation, all substantial economies placed pledges before the international community that they would reduce emissions below business as usual. The sum of the pledges represented a marked departure from established emissions trajectories. At the same time, they were no more than a small first step towards achieving the reductions in emissions that would be necessary to achieve agreed climate change objectives.

The United States pledge represented a large departure from earlier perspectives. President Bush had told a meeting of representatives of large economies in 2007 that United States emissions would continue to rise to a peak in 2025. The Cancun pledge was for emissions to fall from 2005 levels by 17 percent by 2020, corresponding to a 16 percent fall from 2000.

Canada pledged to match a binding commitment by the United States—a substantial undertaking unless the Canadian government had in mind annulling it by saying that the American pledge was not binding even if it were being met.

Some of the pledges contained conditional and unconditional elements—the latter being triggered if other countries took strong action. The European Union pledged to increase its emissions reductions from 20 to 30 percent (both based on 1990) in the context of strong international action.

The Australian pledge was unconditionally to reduce emissions by 5 percent on 2000 levels by 2020, and to increase the reduction to as much as a 25 percent in the context of strong international action. The unconditional commitment represented a sharp break in the trajectory of Australian emissions growth, influenced as it was by the developed world's most rapid growth in population and economic activity and exceptionally rapid expansion of emissions-intensive resource export industries. In 2011, the Australian Department of Climate Change and Energy Efficiency estimated that existing policy, without the new policies legislated in 2011, would see Australian emissions rise by 24 percent.

The Chinese target was to reduce the emissions intensity of economic output by between 40 and 45 percent between 2005 and 2020. This represented the largest departure from business as usual in terms of tonnes of emissions avoided. It could have had a galvanising effect on the Copenhagen meeting at which it was revealed to the international community. That its importance was not noticed and brought to account was a failure of diplomacy in China and many other countries.

Other developing countries made pledges amounting to major changes from business as usual trajectories, with the Brazilian and Indonesian being noteworthy.

The other large developing country, India, made commitments to reductions in emissions intensity that were more modest, but were accompanied by statements that India would never allow per capita emissions to exceed those of developed countries (Planning Commission Government of India, 2011). This formulation would be a powerful instrument of global mitigation in the context of strong action and rapid reduction in emissions across the developed world. It could be usefully incorporated into a global framework for assessing the reasonableness of national contributions to a global mitigation effort.

The various pledges within the context of concerted unilateral mitigation added up to a much larger departure from established emissions trajectories than the notionally binding commitments at Kyoto. However, the pledges left global emissions on trajectories that were far too high for achievement of the two degrees objective unless much more ambitious additional commitments were made for the periods from 2015 and 2020.

Of course, one cannot say now what the Cancun pledges mean for the containment of global warming, as they say nothing about what happens after 2020, and do not allow for the possibility of concerted raising of ambition for what is left of the period before 2020.

Encouraging Progress

There is good and bad news in the story of humanity’s struggle to find a basis for effective collective action on climate mitigation. The early news was never going to be all good on an issue as complex, difficult and new to the international community as this one.

The best news is of immense importance: emissions generally seem to be on paths to meet or exceed the Cancun targets. They are on track to meet or exceed the pledges even in the cases of China and the United States—the world’s biggest emitters of greenhouse gases, the largest and most influential economies, and the pledges of which represent dramatic reductions in established trajectories. Moreover, the achievement of current pledges is being achieved at less cost than was anticipated by most analysts. Early and widely based progress at surprisingly low cost establishes sound foundations for a large and early increase in national mitigation ambition.

Far from reaching a peak in emissions in 2025 as President Bush foreshadowed in 2007, it now seems that United States emissions reached their highest level in the year in which the President was speaking, and have been declining since then. Some have suggested that a decline in economic activity in and following the Great Crash of 2008 has dragged emissions down; the reality is that United States output is now around a tenth higher than in 2007.

Two recent private American studies, by Resources for the Future and the National Resource Defense Counsel, have concluded that the United States is on course to meet its emissions reduction targets despite the defeat in the Congress of the President's proposal for an emissions trading scheme (Scientific American, 2012; National Resource Defense Counsel, 2012). An emissions trading scheme would have allowed the same reduction of emissions at lower cost, but higher cost means can still achieve large reductions in emissions. The Resources for the Future studies attribute 10.5 percentage points of emissions reduction to Federal regulation of mobile and stationery energy, 2.5 percent to State-level regulation and emissions trading schemes and 3.3 percent to the expanded availability of cheap gas and other energy market developments. Since 2009, the United States Government has invested heavily in research and development for new, low-emissions technologies, and this can be expected to be reflected in new opportunities for emissions reductions over time.

Europe has already more or less achieved its Cancun objectives for emissions reductions by 2020. Slow economic growth has subdued demand for emissions-intensive goods and services, but the extent of reduction and the low price of abatement in the emissions trading scheme suggest that emissions reductions have been achieved at lower cost than had been anticipated.

In Japan as in Europe, economic stagnation has contributed to over-performance on emissions reduction goals despite the setback to low emissions energy with the nuclear breakdown at Fukushima. Tokyo's introduction of emissions trading arrangements has been accompanied by especially rapid reductions in emissions which, in turn, has generated extremely low emissions entitlement prices (Rudolph and Kawakatsu, 2012).

In Australia, too, emissions growth has been well below anticipated levels over recent years, tending around zero, despite the continuation of robust expansion of population, output and emissions-intensive resource investment for export. In the electricity sector, stagnant or declining demand has intersected with increased renewable energy production forced by the renewable energy target to cause faster decarbonisation than had been suggested in the official estimates. The introduction of carbon pricing from July 2012 and the use of part of the associated revenue to support renewable energy innovation will extend the reduction in emissions. Preliminary data suggest that emissions from electricity generation in the first six months of the emissions trading scheme are over 8 percent lower than in the corresponding period of the previous year, with slowing demand growth, the renewable energy target and the emissions trading scheme contributing to reductions.

China's 12th Five Year Plan 2011-15 embodies far-reaching measures to constrain emissions within the intensity targets which the Chinese Government has communicated to the international community. In 2011, the first year of the new Plan, emissions continued to grow strongly. This was deeply discouraging for the international mitigation effort. However, policies to give effect to the new Plan began to bite in 2012 and, together with economically driven structural change, changed the emissions trajectory in 2012, to an extent that over-performance against the pledge seems possible and strengthening of the pledges feasible in the context of increased global effort.

Within the electricity sector, accounting for over 44 percent of China's emissions in 2010 (IEA, 2012), demand growth slowed to 5.7 percent in 2012 after demand doubled over the previous decade. The slower growth in demand was in response to energy efficiency and structural policies as well as a moderate easing of output growth (GDP growth 7.9 percent through the course of 2012). The energy efficiency policies and structural change are likely to keep electricity demand growth much lower than in the first decade of the twenty first century, and bring within reach the 3.5 percent annual increase in primary energy consumption necessary to achieve the electricity targets of the 2011-15 Plan.

A Chinese State Council decision added detail to energy plans in early 2013 (Xinhua, 2013). Annual primary energy consumption 2011-2015 would be held to 4.3 percent per annum compared with 6.6 percent through the preceding five years. This corresponds to about 3.5 percent over the next three years. Annual coal consumption will be held to less than 4 billion tonnes by 2015, compared with estimates of 3.8 billion tonnes in 2012. Given the constraints on reducing coal consumption in steel-making and some other industrial activities, this implies some decline in coal combustion for electricity generation.

Table 1 describes the remarkable change in the extent and composition of electric energy growth in 2012.

Table 1. China: Electric Power Generation 2011 and 2012

	2011	**2012**	**Percent Increase**
Total power generation (TWh)	**4692**	**4959**	**5.7**
Thermal	3900	3925	0.6
Hydro	668	800	19.7
Nuclear	87	102	17.2
Wind	74	100	35.8
Other	n/a	32	n/a

Source: NDRC/State Information Center, based on information from the National Energy Administration, January 2013.

Note: ‘Other’ is solar, biomass and geothermal. There was a very large percentage increase in 2012 from a low base (more than one hundred percent for solar photovoltaic), but data on the composition of “Other” are not available for 2011. Note that the components for 2011 exceed the total by a small percentage, but at the time of writing the author has no explanation for this anomaly.

Total electricity demand growth slowed to 5.7 percent in 2012. While early data for 2012 contain some inconsistencies and are subject to revision, they are striking and encouraging. There seems to have been almost no growth in thermal power generation. Output of all low-emissions energy (“clean” energy in the Xinhua terminology) sources of electricity grew rapidly: hydro-electric by 19.7 percent; nuclear by 17.2 percent; wind by 35.8 percent. Solar increased much more rapidly still from a low base. While hydro-electric power generation is affected by climatic conditions which were unfavourable in 2011 and favourable in 2012, it will fluctuate around a rising trend. Nuclear power generation is likely to continue to rapidly increase its share of power generation and wind and solar to do so at an even more rapid rate.

Within thermal power generation, a number of factors led to reductions in greenhouse gas emissions per unit of electricity. A number of Chinese policies will contribute to maintaining the new momentum in reducing emissions from thermal generation that became apparent in 2012. There is still some way to go in replacing high-emissions coal generation in small, inefficient generators with ultra-supercritical plants operating at the world’s efficiency frontiers: the International Energy Agency refers to 68GW of small (less than 100MW) and 138GW of medium (100-300MW) of coal generating capacity remaining in 2010 which is slated for replacement (IEA, 2012). The replacement of inefficient small by efficient large plants reduces both coal use and emissions per unit of electricity output.

Policy is focused on substantially increasing the natural and unconventional gas share of thermal power generation from the current low base. The State Council sees the gas share of primary energy consumption doubling to 7.5 percent by 2020 (Xinhua, 2013), China is investing more heavily than any other country in technological development for carbon capture and storage of carbon dioxide waste from fossil fuel combustion. Deregulation of electricity and coal prices in 2013 accompanied by removal of coal transport subsidies are likely to contribute to easing in electricity demand and to increasing costs of supply from the coal sector. Major investment in high-voltage long-distance transmission and in pumped hydro storage is leading to more complete utilisation of intermittent renewable energy capacity and to expanding options for new investment in renewables. The 12th Five Year Plan greatly increases financial commitments to energy efficiency and for innovation in low-emissions technologies including in the electricity sector.

The electricity supply and demand developments together may have caused zero growth in emissions from combustion of coal in electricity generation in 2012. This is a dramatic break from established trends, of historic importance in global terms. It takes us way outside the conventional wisdom on development of the Chinese energy market.

For example, the International Energy Agency's recent assessment said that China would need to increase coal-based generation capacity from 710 GW in 2010 to 1190 GW in 2020, with total emissions rising despite continued replacement of economically and environmentally inefficient plants by ultra supercritical capacity (IEA, 2012).

In more than three decades of work on Chinese economic growth and structural change in the reform era I have become accustomed to Chinese and foreign observers alike underestimating the capacity of China's economy to respond quickly and powerfully to incentives and to opportunity. The current energy market adjustment seems to be another case of underestimation of the Chinese economy's capacity for rapid transformation in the reform era. Of course, the outcome will depend on the policy that emerges from continuing debates and political contests within China: in the Chinese political system, as in its counterparts in the West, the success of the public interest in shaping policy is sometimes qualified by pressure from vested interests.

The strengthening of policies and actions to change the trajectory of China's greenhouse gas emissions extends over all major sectors.

Industrial emissions, which are largest in steel production, are experiencing much slower growth as a result of policy-enhanced slowing in the rate of growth of heavy industry, and by innovation to reduce emissions intensity. Forced closure of inefficient plants (32 million tonnes of steel capacity alongside 8,000 GW of coal electricity generation in 2011 alone (NDRC 2012)), higher costs of electricity and other inputs, export taxes and restriction of investment in new capacity have slowed expansion in energy-intensive and emissions-intensive activities. The goal articulated in the 12th Five Year Plan to reduce the energy intensity of steel production by a percentage point per annum is a realistic extrapolation of recent trends.

In transport, the heavy investment over the past decade in inter-city and intra-city rail will ease somewhat the growth of automobile traffic from what it would have been. Within the automotive sector, ambitious official targets for electrification are being strongly supported by a range of policies (NDRC, 2012). The combination of rapid expansion of public transport led by rail, automotive electrification and decarbonisation of the electricity sector are likely to add up to unexpectedly early peaking of emissions from the transport sector.

China's and Australia's International Roles

Within concerted unilateral mitigation, it is important for each country to make pledges that are recognised as a fair share in a global mitigation effort, and to deliver on those commitments.

China matters because of its importance as a source of emissions and its economic and strategic weight. China matters because it is likely to have comparative advantage in mass production of capital goods embodying low-emissions technologies: large-scale production of photovoltaic units in China has lowered the cost of solar power generation all over the world, and similar developments are likely in other technologies.

China has become one of the world's main sources of direct foreign investment. Direct investments in transmission by China's State Grid Corporation have greatly reduced the costs of modernising transmission systems in the Philippines, Portugal and Brazil in recent years, and is set to become similarly important in Australia.

Both Australia and China can contribute to innovation in the low-emissions industries. Australia is surprisingly important for its size. Australian research institutions, especially Electrical Engineering at the University of New South Wales, have been at the forefront of applied research in solar technologies, the commercialisation of which has been concentrated in Chinese enterprises. Australia is disproportionately represented in innovation in the biological sciences with relevance to emissions reduction.

Australia matters more than its economic size and strategic weight might suggests because it is one of the three developed countries with exceptionally high emissions per person, which are expected to make substantial reductions in emissions before developing countries do so.

Australia and China are in strong positions to move ahead of others in proposing new ambitions in the global mitigation effort, because they have maintained strong economic growth through the stagnation of most developed economies that followed the Great Crash of 2008.

Australia and China share a strong interest in the nurturing of opportunities for international trade in emissions entitlements. Each has comparative advantage in emissions-intensive activities: China in manufacturing, Australia in tradeable energy. Large-scale exports of emissions-intensive products will tend over time to make both Australia and China relatively large sources of emissions per person. It is economically desirable for these two countries and for the world as a whole that these two countries are able to maintain high levels of exports of emissions-intensive goods, and to meet part of their abatement responsibilities by buying emissions entitlements from other countries.

How can we build on these shared interests and favourable circumstances to improve the chances that humanity is able to manage the anthropocene?

First, we can share views on all aspects of the climate change challenge, as we are doing at this conference. These include views on industrial transformation—including China's experience in upgrading transmission grids to reduce energy losses, to connect energy resources to distant centres of demand, and to integrate intermittent electricity sources more efficiency into the major grids. They include as well experience with mitigation policies (Jotzo, Part 2 of this volume).

Second, we can together take the lead in initiating an independent global analysis of what constitutes a "fair share" of the strong global mitigation effort that will be required to meet the two degrees objective. China and Australia can be among the countries that work together to provide an essential component of successful concerted unilateral mitigation.

Third, we can work together to strengthen the pledges that the substantial economies have made to reduce emissions, and to ensure that international trade in entitlements remains a legitimate means of meeting emissions reduction pledges.

The third area of cooperation is especially important, as the international community faces decisions over the next two years which will determine whether the two degrees objective remains within reach. This paper has explained that marked strengthening of pledges for 2020 and the adoption at Paris in 2015 of strong targets for the period after 2020 are essential to achieve the two degrees objective, to raise prices of traded entitlements to economically and environmentally rational levels and to underwrite a continuing role for domestic and international trade in entitlements.

It is common for commentaries to focus on the failures of international cooperation on climate change. This paper has drawn attention to some successes that could become the launching pad of a strong international effort to bring within reach the agreed objective of holding temperature increases to two degrees.

This paper has drawn attention to the fact that the major economies including China, the United States, the European Union and Japan (despite the setback to nuclear energy at Fukushima) and Australia are making unexpectedly rapid early progress towards realising their pledges to the international community. Reducing emissions is proving to be less costly and disruptive than had been anticipated by expert observers.

The paper has noted the importance of international trade in emissions entitlements in reducing the costs of mitigation for the world as a whole. One weak point in contemporary collective action on climate change is the low prices for carbon units in the European Union and other emissions trading system and in the Clean Development Mechanism. The continuation of low prices would discredit international trade as well as domestic emissions trading systems. The low prices themselves reflect the unexpectedly low cost of reducing emissions.

Of course, there is no problem with low prices if they emerge from targets that are strong enough to achieve the agreed global mitigation objectives. But we are currently far from that point. Current targets fall well short of those necessary to achieve global objectives. In these circumstances, the remedy for prices that are well below the cost and value of optimal abatement is the same as the remedy for a global mitigation effort that currently falls well short of the requirements of the two degrees objective: an early tightening of targets.

The recent rapid progress towards announced targets on emissions reductions in many countries, and the revelation that costs of reducing emissions have been unexpectedly low, together provide the foundations for an early tightening of announced targets in developed and developing countries alike. An international climate change system built around concerted unilateral mitigation provides a favourable context for China and Australia to play their parts in a renewed international effort to achieve the agreed objective of the international community.

The contemporary strength of the Chinese and Australian economies through the long slump in the large developed economies since the Great Crash of 2008 places us in favourable positions to raise these matters for discussion in a wider international community.

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Part 2: Carbon market design and its economic impact

Emissions trading in China: Principles, design options and lessons from international practice

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Abstract

China is considering a national emissions trading scheme, to follow several pilot schemes, as part of the suite of policies to reduce the growth of greenhouse gas emissions. A carbon tax or tax-like scheme could be an alternative. A move towards pricing instruments is significant, in a fast-growing economy where command and control approaches to policy have dominated, and where many aspects of energy pricing are heavily regulated. This paper examines policy design issues for national emissions pricing in China, through emissions trading or alternatively a carbon tax. The paper analyses issues of policy design, in the light of economic principles, China's circumstances and Australian and European experiences. It suggests options for coverage, ways of setting an emissions cap in the context of the national intensity target, options for price management, approaches to permit allocation and revenue use, and discusses the special issues faced in China's electricity sector.

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Summary

China has ambitious goals to limit the growth of greenhouse gas emissions. China's energy and climate policy to date has relied largely on a direct regulatory approach. China is now considering a national emissions trading scheme, and proposals for a national carbon tax have also been raised. Several pilot emissions trading schemes are in preparation. A move towards market based policy instruments is significant, in a fast-growing economy where command and control approaches to policy have dominated, and where many aspects of energy pricing are heavily regulated. China has the opportunity to move to world best practice on carbon pricing, and if successful could encourage other countries to emulate the experience.

This paper examines policy design issues for national emissions pricing in China, through emissions trading or alternatively a carbon tax. The paper analyses issues of policy design, in the light of economic principles, China's circumstances and Australian and European experiences. It finds that:

- Market based instruments for climate change mitigation should be seen in the broader context of economic policy reform and tax reform. These new approaches offer opportunities to support broader goals of economic policy reform, energy policy, environmental and climate policy.
- Achieving emissions reductions at least cost, as typically assumed in economic modelling, in practice requires carefully designed policy frameworks.
- Broad coverage of carbon pricing can improve cost effectiveness. Not all emitters need to be included directly in emissions trading. Upstream permit liability and equivalent emissions charges or taxes may allow increasing coverage while minimising transaction costs and administrative complexity.
- China's dynamic growth and uncertainty about the response of emissions to carbon pricing presents challenges for translating the national intensity target into an absolute cap on emissions in a national emissions trading scheme. The cap (amount of permits issued) may need periodic adjustment in light of GDP growth. Conversely, a carbon tax may result in greater or lesser abatement than anticipated.
- Under a pure trading scheme there would be significant uncertainty about price levels, and potentially large price variability. It is desirable to manage prices at least in the early phases of emissions trading. This could be achieved in a variety of ways. One option is a fixed price model, where government sells permits at a predetermined price; transition to a market based trading scheme is straightforward. A straight carbon tax may also be a viable option. Within a trading scheme, the price can be constrained by a price floor and ceiling; or the permit supply could be made variable to respond to market prices.
- Assistance to industry in the form of free permits (or tax exemptions) to industry needs to be carefully calibrated, in view of incentive effects, the opportunity costs to the budget, and risk of lock-in of assistance arrangements. It is best practice for governments to retain a substantial share of the overall value of emissions permits and in turn to support households,

reduce other taxes, or finance other policy measures. Where free permits and other assistance are given to industry, incentives to reduce emissions need to be preserved, and provisions for review and phase-out of industry assistance are advisable.

- Carbon pricing in electricity supply and demand is necessary for an overall cost-effective response, but presents complex issues for mechanism design and policy implementation because of the interplay with existing regulatory structures in the energy sector, in particular fixed electricity supply prices and mandated dispatch schedules. There are ways to make carbon pricing at least partly effective ahead of comprehensive energy sector reform. Ultimately however, energy sector reform leading to market-based energy pricing is needed.

1 Introduction

China has a goal of reducing the emissions intensity of its economy by 40 to 45 percent from 2005 to 2020, among other goals in the 12th Five-Year Plan to modernise the economy. This is likely to require a significant policy effort (Stern and Jotzo, 2010), and takes place in the context of its international pledge to reduce emissions intensity the Chinese economy (Stern and Jotzo, 2010), objectives to limit climate change risks, improve energy security and gain technology leadership (Boyd, 2012). It also takes place against the backdrop of a broader vision of ‘green growth’ for China (World Bank, 2012). It is technically feasible for China to constrain the growth of its energy use and carbon emissions in the short term, and achieve a peak and decline in emissions in the medium term (Jiang et al 2013). A key question is which policy instruments to apply, and how to design them.

Pricing greenhouse gas emissions through emissions trading scheme or an emissions tax could make a significant contribution to China’s goal of reducing emissions intensity of its economy, and in turn to curbing global greenhouse gas emissions. A move towards market based policy instruments is significant, in a fast-growing economy where climate change mitigation policy has been predominantly by command and control approaches, and where energy pricing is regulated.

Pilot emissions trading schemes are in preparation in seven of China’s provinces and cities (Lo, 2012; Wang, 2012). In 2010 the pilot cities and provinces accounted for around 19% of China’s population, 33% of its GDP, 20% of its energy use, and 16% of its carbon dioxide emissions or about 1.3 Gt carbon dioxide (CO_2) emissions (see Appendix for data and sources). It is not yet clear what share of emissions in the pilot schemes will be covered by emissions trading. The pilot schemes with their different features (see Appendix for an overview) are set to provide a laboratory for gathering experience with different designs and implementation methods, and the effect of emissions pricing in different regional economies.

The bigger opportunity for effective and cost-effective climate change mitigation however is in a national system of emissions pricing. The Chinese government has announced its intention to implement national emissions trading, and analysis on design options is in preparation (PMR 2013).

Emissions pricing holds the promise to reduce emissions at least cost. Yet to be effective in reducing emissions growth at low economic cost, emissions trading needs to be designed to give the correct incentives and according to economic and institutional circumstances, which in China's case poses particular challenges. China has a number of policies in place that constrain carbon emissions, including widespread mandatory standards for energy efficiency and support for renewable energy. It is likely that a price on carbon in China would exist alongside significant non-pricing mitigation policies for some time to come. Depending on the level of the carbon price, non-pricing policies in many sectors could have significantly greater effects than carbon pricing.

This paper sets out principles and investigates options for key design features in China's national and pilot emissions trading schemes. The paper covers the extent of coverage of the carbon market and alternative ways of implementing a carbon price (section 2); how to set emissions caps in the context of fast economic growth and targets framed in intensity terms (section 3); whether and how to manage prices in emissions markets (section 4); methods of allocating permits and decisions about using revenue (section 5); and some of the particular issues arising for the electricity sector in the context of regulated prices (section 6).

The paper draws on experience in existing carbon pricing schemes, in particular the Australian carbon pricing scheme (Australian Government, 2011a; Australian Parliament, 2011; Garnaut, 2011, 2008; Jotzo, 2012) and the European Union's emissions trading scheme (Ellerman and Buchner, 2007; European Commission Climate Action, 2012). Each section includes a consideration of principles on specific issues of policy design, a brief summary of relevant international experiences, a brief indication of future research needs, and a discussion of implications for a potential future Chinese national emissions trading scheme. The analysis is to a large extent equally applicable to pilot emissions trading schemes.

2 Coverage of emissions trading

Key messages:

- *For overall effectiveness and cost effectiveness, it is important to cover a large share of emissions under a carbon pricing scheme.*
- *Direct permit liability under ETS is not the only option for carbon pricing. Alternatives such as upstream liability for fossil fuel emissions or carbon price equivalent charges for other emissions can overcome hurdles to inclusion and improve overall cost effectiveness.*

The primary aim of a carbon market is to provide incentives to reduce emissions at lowest cost. In principle, the broader the application of a homogenous emissions price, the greater the cost effectiveness of the overall abatement response. This applies both to regions, with cost savings from uniform application of carbon pricing across China's provinces (Zhang et al., 2012), as well as to coverage of different sectors of the economy, which is examined here.

However, it can be preferable not to include small emissions sources directly in the permit scheme because transaction costs are likely to be too high. It may be possible to include them indirectly through upstream permit liability on fossil fuel distribution, or through carbon equivalent charges or taxes. Furthermore, there may be specific sectors where other policy instruments are needed in addition to, or instead of, a carbon price.

2.1 Sectoral coverage

Carbon markets can create a consistent price signal across a wide range of economic activities. The broader the coverage of emissions sources, the broader the incentive to reduce emissions.

However, carbon pricing will also result in transaction costs, in particular for the monitoring, reporting and verification (MRV) of emissions levels from each individual source (installation) covered. Where sources are small and/or difficult to monitor because of the nature of their activity, effective inclusion may not be possible, or only at large transactions costs. An overall cost-effective carbon pricing scheme may exclude some sources for this reason.

There is also a role for non-pricing instruments. Standards and other regulations may usefully apply in sectors such as agriculture where emissions pricing is impracticable because of measurement issues at the business level; in promoting greater energy efficiency in end-use applications where price signals cannot overcome the hurdles to adoption of efficient technology even if they are economical, for example because of incentive structures or institutional barriers; and in areas such as transport where public investment in infrastructure may be the most important mechanism for climate change mitigation.

Prerequisites for inclusion

The prerequisites for inclusion of a source of greenhouse gas emissions in a trading scheme include the following:

- Emissions data: emissions from each source of emissions need to be measurable to a sufficient degree of accuracy and reliability.
- Transaction costs: the cost of monitoring, reporting and verification (MRV) of emissions, and fulfilling the administrative requirements for taking part in emissions trading, needs to be lower than the gain in overall cost effectiveness from including a particular emissions source. Where direct coverage is uneconomical, upstream coverage or coverage through carbon-equivalent charges or taxes (discussed below) may be appropriate.

It is possible to extend the sectoral coverage of an ETS over time, for example starting with sectors where MRV is relatively straightforward and that cover a relatively large share of emissions.

Plans for future expansions in scope should be clearly signposted so the market can anticipate potential changes in market conditions. This is similar as for changes over time in the scheme cap (see Section 3).

International practice

Most existing emissions trading schemes (ETS) cover emissions from fossil fuel combustion in electricity production and industry, as well as fuel use in heavy industries. This is in line with these emissions sources being large; measurement being relatively accurate, easy and low cost; and there being plentiful abatement options in response to a price on emissions.

Greenhouse gas emissions from various industrial processes are covered under the Australian scheme. In the EU ETS, coverage is extended to some industrial processes in the scheme’s third phase from 2013.Emissions from transport are covered within the existing schemes only in Australia and there only partially. However all countries with carbon pricing schemes also have fuel taxation for transport in place, at much higher levels per unit of fuel than a carbon equivalent price would pose. Carbon pricing needs to be considered in the context of existing taxes and subsidies, a point discussed further below.

Among the existing carbon trading schemes, at this stage only the NZ ETS includes parts of agriculture, as well as forestry (on an opt-in basis). Usually, practical difficulties in MRV of small and dispersed sources is the reason, however political considerations in imposing costs on agriculture may also have played a role in the policy decision not to include the sector. Technical difficulties with inclusion of agriculture as well as forestry include the accurate measurement of emissions at the farm or plot level, and enforcement of permit liability. It can also be politically difficult to impose permit liabilities on the land-based industries.

The Australian scheme also covers emissions of carbon dioxide (CO_2) and other greenhouse gases from industrial processes, mining and landfills. This represents more comprehensive coverage than any other existing ETS. Gas combustion by households and parts of the transport sector is also included, by way of upstream coverage and carbon equivalent tax changes (see below).

2.2 Size threshold for inclusion in ETS

Existing ETS have a cut-off for the size of individual installations included with direct permit liability. This allows including only the larger emitters as liable entities, limiting the number of participants in the market. It limits the administrative effort for government and overall compliance costs to industry.

But limiting inclusion to large emitters creates distortions between large and small emitters. There is a threshold effect whereby installations may have an incentive to reduce their operations so that emissions are below the cutoff; and reduced overall effectiveness because small sources do not have incentives to reduce emissions.

A lower threshold for inclusion means a much larger number of liable entities, but only a modest increase in the share of total emissions covered; conversely a higher threshold reduces the number of liable entities by much more than the share of emissions covered. In other words, the incremental gain in coverage is small as the threshold is reduced, while the incremental increase in transaction costs is large.

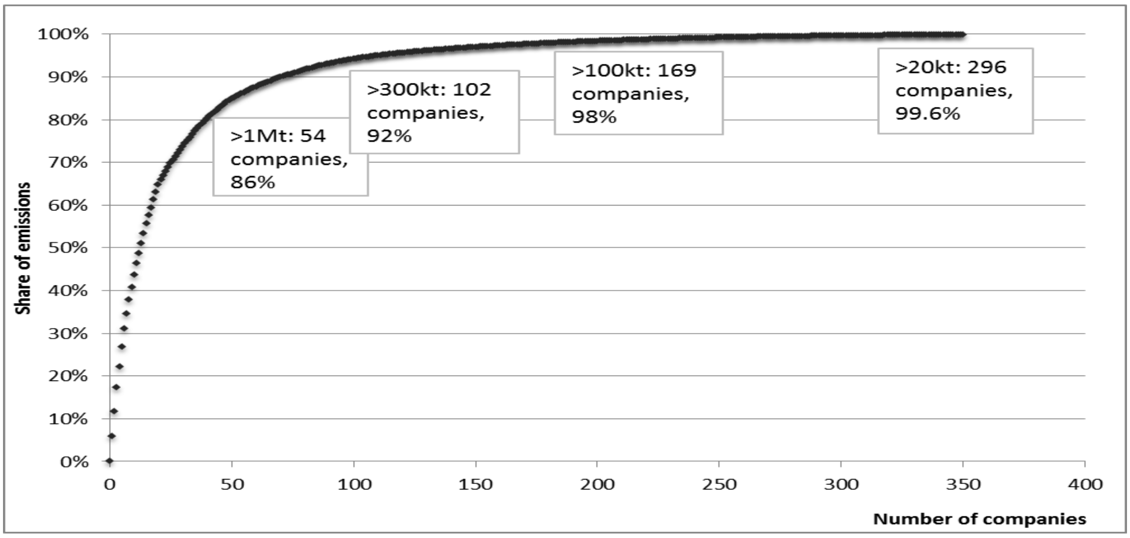
International practice

The cut-off for direct liability in the EU ETS is 25 kt CO_2 per year, with over 11,000 installations covered; and equally it is 25 kt CO_2-equivalent per year in the Australian scheme, with 374 installations covered.[5] There are some indications that the EU scheme includes many installations that are too small to effectively take part in emissions trading, with a large share of emitters having neither evaluated their options to reduce emissions nor implemented reduction measures, and transaction costs amounting to a significant share of total compliance costs for the small emitters included in the scheme.

As illustrated in Figure 1, in Australia a threshold of 300kt/year would have covered 92% of emissions under the National Greenhouse Gas Reporting System (fossil fuel and industrial emissions, during 2010-11), from around 100 companies; whereas a threshold of 20kt/year encompasses around 300 companies, with the extra 200 companies raising the amount of covered emissions by only 8 percentage points. This suggests that choosing a higher threshold might have reduced the administrative cost without greatly diminishing abatement, though excluding more emitters would create greater distortions between companies of different size.

Higher thresholds are a particularly promising proposition if there are provisions for covering smaller emitters, as discussed below.

Figure 1 Cumulative emissions for Australia's largest emitting companies



Data source: Australia's National Greenhouse Gas Reporting System, 2010-11 data (emissions from fossil fuel and industrial processes).

5 As of 10 April 2013.

2.3 Upstream coverage of emissions from fossil fuels

As an alternative to the standard model of covering emissions at the point where CO_2 is emitted into the atmosphere, emissions from fossil fuel use can be covered at an earlier point of the carbon supply chain. Specifically, a carbon price can be imposed at the level of coal mines and coal import terminals; oil refineries; and gas distribution hubs. This is referred to as 'upstream' coverage, in contrast to 'downstream' coverage where emissions are subject to a permit liability at the point of fuel combustion.

Under upstream carbon pricing, the suppliers of fossil fuels have to acquit carbon permits for the emissions embodied in the fuels that they sell to their customers. They reflect the cost of the carbon in the price they charge their customers. As a result, the same incentives and distribution of costs as under downstream coverage is achieved: the carbon cost is borne by industries that use energy and end users of the resulting products and services rather than by the fuel suppliers. The users of fuels have the incentive to reduce energy consumption and move to lower-carbon energy.

The advantage of upstream coverage is that it can drastically reduce the number of compliance points compared to downstream coverage. It thereby makes MRV easier and reduces transaction costs. It also allows coverage of practically all uses of fossil fuels, even by very small users such as small companies and households, which would not be practically possible under a pure downstream system.

The prerequisite is that carbon costs imposed on fuel distributors can effectively be passed on to fuel users by way of price increases, so that the end users have the correct incentives to reduce their use of emissions intensive energy. If cost-pass through is ruled out through regulation – for example where fuel supply prices are fixed – upstream emissions pricing will reduce suppliers' profits without resulting in changed consumption patterns, because end users to not see an price signal for their emissions. Where price pass-through is only partial, for example because of market power in fuel or electricity supply, upstream emissions pricing will generally result in a partial price signal for end users.

Upstream and downstream permit liability can be combined, by implementing upstream liability while also covering large users of fossil fuels directly and exempting their fuel supplies from the upstream liability. This can be desirable in the case where large users of fossil fuels prefer to manage their own permit liability rather than paying higher prices. Reasons may include that large emitters can then integrate permit liability for all sources of emissions from their operations, or because they feel can better manage financial risks through strategies such as forward purchases of permits.

International practice

In the Australian carbon pricing mechanism, a mixed upstream/downstream system is in place for the use of natural gas in the economy. Individual installations with emissions greater than 25 kt CO_2-equivalent per year are under a direct liability for their emissions. The suppliers of natural gas get an exemption from carbon liability for the gas supplied to large users who manage their own permit liability.

2.4 Equivalent carbon charges or taxes

An ETS operating in some parts of the economy can be complemented by carbon taxes or charges, on other sources of emissions.

This may be suitable in cases where

- It is not feasible or desirable to include certain types of emissions sources in the trading scheme,
- Emissions accounting does not achieve the level of reliability required in the ETS overall but to an acceptable level for taxation of individual emissions sources, and/or
- There are systems for charges or taxation of the relevant activities already in place which can easily be adapted to put a price on emissions, thus saving on transaction costs.

An equivalent tax or levy system applied to some sectors may create the need for periodic adjustment of tax rates which may be undesirable; conversely it creates the opportunity for more price stability which may be desired.

Arrangements for assistance to industry can be designed equivalent to those under ETS. Under a permit scheme, assistance is typically delivered in the form of free permits. Under carbon taxes or charges, assistance can take the form of tax-free thresholds[6], or a defined cash subsidy.

The key advantages (compared to inclusion in the ETS) are greater administrative simplicity, the potential to cover a greater extent of sources, as well as potentially the greater stability in prices over time and leeway to let prices deviate from ETS prices. Potential disadvantages compared to inclusion in ETS (where this is possible) are that the depth of the domestic carbon market is diminished, and that sectors covered by a tax and charges are not able to directly participate in international permit markets. Furthermore if carbon charges deviate strongly from market prices there may be some overall losses in efficiency of the mitigation response.

The factors for the choice of different forms of coverage – direct permit liability, upstream liability, and equivalent charges – are summarised in Table 1.

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6 For a fully efficient abatement response, these tax thresholds should be allocated as a right that is tradable between emitters (Pezzey, 1992).

International practice

Australia is imposing an equivalent carbon levy on some synthetic greenhouse gases, and on liquid fuels used for some types of transport. In both cases, tax or levy arrangements already exist that cover the production or use of products that cause greenhouse gas emissions.

Several European countries have had separate carbon taxes on parts or all of their fossil fuel use, and have kept them in place once the ETS started. This leads to a higher effective carbon price in these countries, and for the relevant activities, than where only the emissions trading scheme applies.

Table 1 Different forms of coverage

	Direct permit liability	**Upstream liability for fossil fuels**	**Equivalent charges/taxes**
Key features	Companies are liable to acquit permits for emissions from their installations.	Distributors of fossil fuels are liable to acquit permits for emissions inherent in the fuels they sell. Point of liability: fuel distribution (or alternatively fuel production and imports).	A tax or levy is applied to particular emissions sources not included in an emissions trading scheme.
Applicability	Any greenhouse gas emissions. Impractical for very small sources of emissions.	Natural gas, diesel, petrol; possibly coal. Large emitters can be exempt from upstream coverage and manage their own permit liability.	Any sources of greenhouse gas emissions. Attractive where MRV is not of a high enough standard to enter ETS, or where charges or taxes already exist for the relevant emitting activities.
Prerequisites	MRV at the level of emitting installations.	Pass-through of permit costs to users of fossil fuels. MRV at the level of fuel distributors.	MRV at the level of emitting installations.
Advantages	Maximum depth of emissions trading market. Ensures that all emitters face the same carbon price.	Allows coverage of 100% of fossil fuel emissions at modest transaction costs. The number of liable entities is much smaller than for direct coverage.	Expands coverage of carbon pricing without including extra participants in ETS.
Disadvantages	High transaction and	Less depth in the	Less market depth.

	administrative costs for small sources of emissions.	emissions trading market (though this can be addressed by allowing direct liability for large emitters).	Efficiency losses if carbon charges deviate strongly from market prices.
Examples	All existing ETS	Australia: natural gas	Australia: some transport fuels and industrial gases

2.5 Considerations for China on ETS coverage

Sectoral coverage

On the basis of principles and international experience, it is advisable for China to seek broad coverage of its carbon pricing scheme, including the production and consumption of electricity, direct use of fossil fuels in industry, industrial process emissions, and possibly fossil fuels used for transports and by households.

However, this is not necessarily best achieved through direct permit liability of all emitters. Rather, China should consider extensive use of upstream liability for emissions inherent in fossil fuels, at the refinery or fuel distribution level; and equivalent carbon taxes or charges for selected other types of emissions. This can serve to expand coverage while reducing administrative complexity and transaction costs.

Phased introduction of carbon pricing to different sectors may be advisable. Carbon pricing can start out covering a core group of sectors, and then be expanded as experience is gained and as the prerequisites for inclusion of other sectors and greenhouse gas emitting activities are established.

Upstream coverage and thresholds for direct inclusion

For China it is advisable to consider a relatively high threshold level for direct inclusion in an ETS, and in turn to include smaller entities through upstream coverage of fossil fuel use. This approach could achieve up to 100% coverage of emissions from fossil fuel use, while keeping the number of market participants manageable, and transactions costs and administrative burdens low.

For pilot schemes in cities, where the majority of overall emissions will typically come from a relatively large number of medium to small emitters rather than a small number of large emitters, upstream approaches may be particularly attractive.

A key prerequisite for the upstream approach is that fuel providers are able to raise their product prices in order to accurately reflect the carbon costs. This is best achieved in liberalised energy markets. In a system of regulated energy prices, an approximate outcome can be achieved if the mandated energy prices are adjusted for the cost of carbon permits. The special case of power generation is discussed in more detail in Section 6 below.

Equivalent carbon taxes or charges

China may want to consider raising taxes or charges on greenhouse gas emissions equivalent to a carbon price under the ETS where direct inclusion in the carbon market is not desired, or not possible for example because of difficulties in MRV. Examples may include industrial process emissions.

Special considerations for pilot schemes

Decisions about coverage of emissions in China's pilot ETS schemes should generally follow the criteria laid out above. However, there are particular issues to be considered with regard to the power sector and heavy industries.

The pilot scheme areas are linked into power grids that are supplied in large part by electricity generators located outside of each scheme. This complicates the application of carbon pricing on electricity generators. Meanwhile most pilot schemes are planning to put a price on "indirect emissions" from electricity. Such demand side carbon pricing is possible through the modes of direct liability of large users, upstream liability, or equivalent charges, and the same considerations as laid out above apply. Section 6 provides further detail.

Effects on emissions intensive traded goods industries within the pilot schemes could be of interest for the two pilot provinces, which have significant heavy industries, and less so for the five pilot cities. Depending on the scheme design, emissions-intensive industries could be at a competitive disadvantage relative to producers in provinces that do not impose a carbon price. However, given the expectation of a national carbon pricing scheme this is only a temporary issue that is unlikely to lead to significant unwanted relocation of industrial production. Any temporary distortions also need to be considered in the broader context of existing non-pricing policies, which will often have a much larger effect on location decisions than temporary differences in carbon prices.

In many cases, local jurisdictions may even wish to speed up the process of industrialing restructuring towards higher value added, less energy intensive and less polluting industries.

Research needs

Quantitative research is needed on the amount and cost of abatement likely to be achieved from different sectors. This can be done using top-down computable general equilibrium models, and bottom-up engineering-economic models. Useful research questions for modelling applications include

- What is the relative contribution of different sectors of the economy to overall abatement, at different carbon price levels – in absolute and percentage terms?

- What is the relative importance of different aspects of abatement action, eg fuel switching, energy efficiency improvements, and changes in the composition of supply and demand for goods and services as a result of a carbon price?
- How does the cost of achieving a given amount of overall abatement depend on the extent of coverage; what is the cost advantage of broader coverage?

Further quantitative research is indicated on the likely magnitude of transaction costs and administrative costs in various sectors, for different thresholds for inclusion in ETS, and for the different modes of coverage. These aspects of cost are usually not included in the modelling of mitigation, but need to be considered in deciding optimal coverage.

This research needs to be complemented with qualitative research on the institutional feasibility of coverage through different modes of coverage in different sectors, to help decide what extent of coverage is feasible in practice. Experiences in the pilot schemes can be a valuable source of information in making coverage decisions for a national scheme. Research could investigate the actions taken, and transaction costs incurred, of companies of different sizes and in different industries.

3 Setting an emissions cap and trajectory

Key messages:

- *In order to help achieve a national emissions intensity target, the caps on permits will usefully be indexed in some form to realised GDP growth.*
- *Flexibility mechanisms such as banking or borrowing of permits are desirable in principle.*
- *Because of uncertainty about future growth and abatement responses, it may be desirable to combine the cap on emissions with price control mechanisms that may override the cap.*

3.1 The function of the cap

A carbon market is created by government requiring emitters to cover their carbon emissions with permits, and by issuing a limited amount of permits. The ‘cap’ is the amount of emissions permits issued over the period of one year, with a succession of annual caps amounting to a ‘trajectory’. Government can allow emissions permits issued in earlier years to be used in later years, or vice versa (banking and borrowing respectively, see Section 3.4).

Setting an emissions cap and future trajectory presents particular challenges for China, for two reasons.

Firstly, national and regional emissions targets are framed in emissions intensity terms, while an ETS would usually function on the basis of permits for absolute amounts of emissions. The sectors under the cap may amount to a significant portion of the total national (or regional) emissions target, and so the absolute cap should follow the overall intensity target. How an absolute cap could be set on the basis of an intensity target is discussed in 3.2.

Secondly, China faces large uncertainties about future emissions trajectories because of its rapid economic growth and rapid structural change, change in policy settings that affect energy use and carbon emissions, and because there is not yet any experience with the effect of carbon pricing on emissions levels. As a result, projections of future emissions levels and thus the abatement task from a given cap, and projections of emissions price resulting from a given cap, are highly uncertain.

Policymakers and industry may not be comfortable with a the possibility that the carbon price in markets may be either very high or very low, and instead may want to put bounds on the price – which in turn means overriding the cap. Price management mechanisms are discussed in Section 4.

3.2 The relationship between the permit cap and a national emissions target

An ETS will not cover all emissions sources in an economy and it will usually also not include all emissions covered by a national emissions target. Therefore, the percentage reduction change under the cap is not necessarily the same as the percentage change targeted for national emissions. In other words, setting a specific cap for the carbon market does not automatically assure that a specific national target will be met, because there could be surprises in the non-covered sector. If the non-covered emissions grow faster than the overall target, then the emissions under the cap need to grow more slowly, implying a smaller cap (and vice versa).

In China’s case, the national emissions target for 2020 as currently defined ranges only over carbon dioxide from fossil fuel combustion. As a result, it is more readily possible for a carbon market to cover a large share of emissions under the target, because other greenhouse gases, agriculture and forestry are separate from the headline target. If a national carbon market covers most or all of the emissions under the target, then setting the cap in accordance with the target assures that the target will be met.

However, the fact that China’s national target is framed in terms of emissions intensity introduces specific complexities in setting caps for a carbon market.

International practice

In the EU ETS, an annual decrease in the emissions cap is legislated. The rate of decrease of 1.74% per year is calibrated to the EU target of a 20% reduction in emissions from 1990 to 2020. In the Australian scheme, there is a legislated default trajectory for the scheme cap. The default reduction in the cap over the years 2015-20 is about one third.

Beyond the initial period of scheme caps, there will be rolling 5-year periods of scheme caps. The government will be required to make regulations each year for the following five years, taking into account recommendations by the independent Climate Change Authority. This approach strikes a balance between providing predictability to the market, and adjusting the cap over time to take account of changed circumstances. Furthermore, Australia expects international trading to play a large role in covering the gap between emissions under the ETS and the overall national target.

3.3 Absolute caps and intensity targets

China's national target is framed as an intensity target (40 to 45% reduction in the ratio of emissions to GDP, from 2005 to 2020). This can be translated into a target framed in absolute emissions levels, by assuming a future rate of growth of GDP (Jotzo and Pezzey 2007). However, the actual amount of emissions allowed under the target will inevitably differ from forecasts, as realised GDP growth invariably will differ from that assumed.

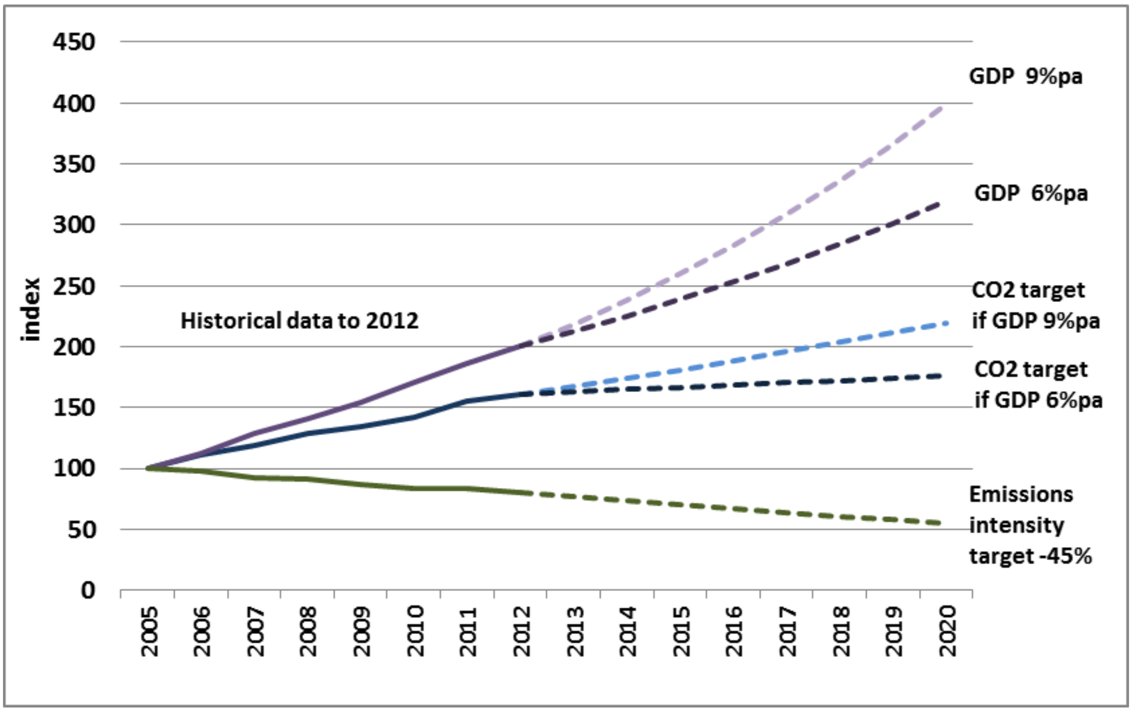
Given China's high growth rates and rapid structural change, uncertainty over future GDP growth rates is substantial, and so is uncertainty over the absolute amount of emissions under the national target. For example, if GDP were to grow at an average annual rate of 9% between 2013 and 2020, then reducing emissions intensity by 45% over the period 2005 to 2020 implies that absolute emissions in China are allowed to increase by 36% from 2012 levels to 2020, or about 4% per year.

By contrast, if GDP were to grow at an average rate of just 6% per year during 2013 to 2020, the same intensity target implies an increase in emissions of only 9% over 2012 levels, or just 1% per year over the remainder of the decade. This is illustrated in Figure 2.

In previous years such "slow" growth scenarios have often been seen as unrealistic, however signs are emerging that Chinese GDP growth is moderating, and that the Chinese government may prioritise the quality of growth over maximising the rate of economic expansion. Several institutions see Chinese growth potential for the decade in the range of 6% to 8% per annum (Huang 2013).

It should be noted that continued structural change towards less energy and emissions-intensive activities (Garnaut, 2012) is a key opportunity for China to meet, and potentially exceed, its 2020 emissions target. If coupled with continued improvements in energy efficiency and a sustained shift to lower-carbon energy sources, it may enable China to begin reducing absolute emissions levels.

Figure 2 Illustrative trajectories for GDP and emissions to meet a 45% reduction in emissions intensity from 2005 to 2020



Note: Computed on the basis of a 100% increase in GDP from 2005 to 2012, and a 59% increase in China's CO_2 emissions from fossil fuel combustion from 2005 to 2012, implying a 21% reduction in emissions intensity from 2005 to 2012. Data: GDP – IMF World Economic Outlook database October 2012 (GDP in constant local currency); emissions - IEA "CO2 highlights 2012" to 2010, IEA media release for 2011, Chinese government announcements in January 2013 of GDP growth 7.8% during 2012 and a 5% reduction in emissions intensity during 2012.

There are two in-principle ways to deal with this issue in setting a cap:

1. A fixed, pre-defined absolute cap based on expected GDP. The eventual difference with the national target would be covered through other means – such as greater or lesser policy action in sectors not covered by the ETS, international trading of emissions units, or simply accepting a divergence between actual emissions and the national target.
2. Indexation of the cap to GDP. Either by defining the cap as an absolute amount of permits based on expected future GDP, and making adjustments to the cap over time, based on actual GDP growth; or by making the scheme cap a direct function of GDP growth, in line with the national intensity target.

If an ETS were to be used as the principal means of achieving a national emissions intensity target, then it is logical to calibrate the cap for emissions permits to the actual level of emissions allowed under the national target, and thereby to actual GDP growth.

There are a variety of possible ways how the scheme cap could be indexed to GDP, and possibly to changed expectations about future GDP. One way would be to define a default cap trajectory based on expected GDP growth rates, and to adjust the cap for each year by correcting for the difference between expected and actual GDP for the previous year:

$$adjusted\_cap_t = default\_cap_t * (\frac{actual\_GDP_{t-1}}{expected\_GDP_{t-1}})$$

Whichever form of GDP indexation is chosen, the cap should be computed in accordance with rules that are defined in advance, rather than through ad-hoc adjustments (as could be the case with proposed changes to the EU ETS cap). This is in order to allow carbon markets to form clear expectations about the amount of permits that will be available, on the basis of observable variables, without introducing policy uncertainty.

3.4 Permit banking and borrowing

Banking and borrowing of permits provide inter-temporal flexibility in the compliance with an emissions cap. They effectively allow markets to smooth prices over time, by defining emissions caps over longer time periods than the annual amount of permits released.

The owners of emissions permits may decide to hold onto it for future use ('banking' of permits). Banking of permits effectively means that a share of the permit supply is taken out of circulation, keeping present emissions levels below the cap, but potentially increasing future emissions levels above the cap. Conversely, a government may decide to allow emitters to defer the fulfillment of part of their emissions liability by handing in extra permits in future years. This amounts to 'borrowing' of permits.

The theory and practical experience of commodity and financial markets suggests that (absent any shocks technological changes, new information or changes in policy) intertemporal flexibility by way of banking and borrowing will allow the market price of permits to rise smoothly along a forward price curve ('Hotelling' curve). Any new information about abatement costs, technological changes or policy changes is then represented as an upward or downward shift of the entire forward price curve, rather than larger adjustments during shorter time periods as would be the case without banking or borrowing.

Furthermore, banking and borrowing allows for a smooth transition between different phases of an emissions trading scheme, where the effective stringency of the mitigation commitment will differ (eg 2013-15, 2015-2020, and so forth). If banking or borrowing is not allowed between different periods of a trading scheme, then the market price will show a discontinuity between the different phases.

International practice

Banking tends to be allowed in practice, but often with limits. Banking has sometimes not been allowed past a specific point in time, leading to disjointed price trajectories over time. For example, the price of permits in the first phase of the EU emissions trading scheme (2005-07) fell to zero when it became clear that there was an oversupply. Banking into the second phase (2008-12) was prohibited, and so the permit demand in second demand could not support prices in the first period.

Borrowing in existing schemes is typically restricted to small amounts, for fear that large amounts of borrowing could defer mitigation action too far into the future, and that it might create a self-fulfilling expectation that governments will not enforce the policy.

3.5 Considerations for China on setting caps

Given China’s national emissions intensity target, it may be useful to adjust annual emissions caps in a national emissions trading scheme in the light of realised GDP, so that the emissions cap more closely tracks the national emissions target. This should ideally be done using transparent, pre-announced formulas so that markets can form expectations about future permit supply without additional policy uncertainty.

Allowing banking and borrowing of permits between years, and ideally between phases of the ETS, provides intertemporal flexibility and allows a smooth movement of the permit price through time. Some extent of banking, and possibly borrowing, is likely to be desirable in order to reconcile the trajectory of annual caps with the level of actual emissions which cannot be known in advance.

Research needs

Quantitative analysis and modelling will be needed on various aspects of likely future emissions trajectories and mitigation responses in order to inform the setting of ETS caps and rules such as for banking and borrowing.

Research questions include:

- What is the likely range of emissions growth scenarios of emissions outside of the ETS, given the policies that apply to these emissions sources (this determines the allowable emissions under the cap for a given overall target)
- How does the extent of coverage of the ETS affect emissions growth outside of the ETS
- How does the underlying growth rate in emissions, inside and outside of the ETS, change in response to slower or faster GDP growth
- What is the likely trajectory of emissions growth inside the ETS, in response to an emissions price (this in part determines banking and borrowing).

CGE modelling, and partial sector specific models and projections – in particular for the energy sector – and regression-based analysis can all be useful in conducting such analysis. The analysis will generally be need to be conducted from a stochastic viewpoint, identifying ranges and likelihoods rather than just expected values.

4 Price management and market stabilisation

Key messages:

- *Hybrid schemes with elements of both emissions control by quantity and price instruments are possible.*
- *There are different options for price management within an emissions trading scheme, including fixed price permit schemes, price floors and ceilings, and variable permit supply.*
- *For China, letting the market price float in line with other international markets and long-term price expectations could be desirable in the longer term.*
- *During the early phases of a national ETS however, there is likely to be significant uncertainty over the relationship between emissions caps and permit prices, and potentially high permit price variability. This may make it desirable to implement price management mechanisms to retain the carbon price within a "comfort zone".*

4.1 Price control, quantity control and hybrid schemes

An emissions trading scheme is traditionally predicated on the notion that emissions should not exceed a predetermined level within the scheme (the cap). However, it is *ex ante* unclear what will be the required emissions price to achieve this outcome, so the permit price resulting in markets may diverge significantly from prior expectations.

If underlying emissions trends turns out lower than the target, and/or emissions reductions turn out be cheap, then the price will be lower than anticipated, and could even be zero. In this case, it may be desired to increase the abatement ambition of the scheme to achieve greater emissions reduction, because a lower level of emissions can be achieved at the expected cost. Conversely, if underlying growth is stronger than expected and/or the cost of reducing emissions is higher, the emissions trading price could be very much higher than expected. In that case, it may be desired to ease off on the ambition of the abatement target, in order to avoid a cost-overrun.

On the basis of expected costs and benefits under uncertainty, economic theory provides a clear case that for global greenhouse gas emissions by price control is preferable to quantity control (Weitzman, 1974).

However from the perspective of applied climate policymaking for one country, the arguments from economic theory about global mitigation mechanism choice do not hold strong relevance because global efficiency of mitigation effort is typically a secondary consideration for individual national governments, and because emissions targets can be adjusted over time. There is often a preference for trading schemes over taxes, either because of negative political perceptions of taxes, because of a desire to frame mitigation action in terms of its quantitative outcomes, or because of an objective to manage business liabilities in markets.

However, notwithstanding the preferences for quantity control that may underlie the choice of ETS rather than carbon taxes as the preferred policy instrument, governments and business often also have a preference for controlling the permit price, at least to some extent. There may be a sense of a "comfort zone" for the carbon price within which an adequate amount of mitigation is achieved, while avoiding overly high costs. A related issue is market stabilisation in the sense of avoiding overly large fluctuations in the permit price.

Together, these factors point to a preference for 'hybrid' instruments of emissions control (Roberts and Spence, 1976), and shown to have economically desirable properties in empirical analysis (Philibert, 2009; Pizer, 2002).

4.2 Uncertainties about the abatement task and the cost of reducing emissions

The amount of effort needed to achieve a given emissions target depends on the underlying growth momentum of emissions. This in turn depends on the rate of economic growth, the nature and speed of structural change, and of technological innovations. All of these are uncertain, and reality often deviates from projections by much more than analysts and policymakers think it might. Recent examples include the economic slowdown and resulting drop in energy demand in the United States and Europe, as well as the rapid development of unconventional natural gas.

The second factor of uncertainty is about the response of the economy to a given carbon price, or conversely the cost of achieving a given amount of abatement. Experiences with market-based instruments for pollution control have shown that abatement is usually cheaper than expected ex-ante, in many cases much cheaper than projected (Daley and Edis, 2010).

Together, these two sources of uncertainty mean that there is great uncertainty about the permit price that might result in a ETS from a given cap and trajectory. The recent dramatic fall in EU ETS permit prices, and the collapse in the price for credits from the Clean Development Mechanism, are powerful examples.

The uncertainty is likely to be particularly large for Chinese pilot trading schemes, because variability in underlying emissions growth is greater than in most developed countries; because there is not yet any experience with the effect of carbon pricing on emissions in China; and because uncertainty about future policy settings can limit price smoothing through time by way of banking or borrowing .

In the case where emissions targets (caps) are set relatively close to the expected business-as-usual emissions trajectory, there can be a significant probability of emissions remaining below the cap even without any mitigation action induced by a price signal. In this case, the permit price could remain at or close to zero.

4.3 Fixed price permit scheme

It is possible to fully determine the price in a permit scheme. In this case, the carbon price is effectively equivalent to a carbon tax, but it uses the institutional infrastructure of a permit price. This allows to easily transform the scheme to trading with a market price, and also makes it readily possible to allocate free permits.

To implement a fixed price permit scheme, emitters are placed under a liability to acquit permits for their emissions just like in an ETS. However rather than buying permits at auction or in markets at a market price, permits are for sale from government at a predetermined ('fixed') price. There is no cap on the amount of overall permits, the government sells however many permits are demanded by emitters. There would usually not be banking of permits for future periods, otherwise the fixed price in one year could put a lower bound on the permit price in future years. There would usually also not be any trading of emissions permits with other jurisdictions. Companies needing to purchase permits would usually make their purchases at the same time that their permit liability comes due.

The advantage of full price control by way of a fixed price scheme is that it provides greatest possible predictability of the economic effects of the scheme, such as impacts on consumer prices and compliance costs for emitters. It can thereby be useful to better calibrate cash payments that are independent of market prices, and help in communicating the likely effects of the policy before introduction. It does however provide no feedback loop from emissions levels to the stringency of the carbon price. A fixed price scheme may turn out to achieve much greater or much smaller emissions reductions than desired.

International practice

Australia's carbon pricing scheme starts with a fixed price, applicable during an initial three-year period (Australian Government, 2011a) . From mid-2012 to mid-2015, the scheme operates with a government determined price starting at A$23 per tonne of CO_2 equivalent and rising to A$25.40/t. (RMB 147/tonne – 163/tonne). The Australian government sells an unlimited amount of permits at this price, so there is no cap on the amount of permits issued. Neither international trading nor banking of permits is allowed.

Thus, during the first three years the scheme acts like a carbon tax, but it uses the institutional and legal infrastructure of a permit system. It therefore allows ready transition to a market-based trading scheme. The fixed price model allowed breaking a deadlock in negotiations between the government and Greens party, who could not agree on Australia's national target and a quantitative cap for the permit scheme, but could agree on a price to get the scheme started

(Australian Government, 2011a). Australia's fixed price also makes fiscal revenues and impacts on price levels more predictable, and allows more time to prepare for market-based trading. No other significant ETS to date has used a fixed price model. Initial experiences from Australia show that the fixed price in practice functions as expected.

4.4 Price floor and price ceiling (hybrids)

Emissions control by quantity and price instruments can be combined in 'hybrid' schemes. The classic form is a system that confines the market price to a range between a minimum (floor) and maximum (ceiling) price. This is sometimes referred to as a 'price collar' (Jotzo, 2011; McKibbin et al., 2009).

A *price floor* ensures that a minimum extent of incentives to reduce emissions is achieved, independent of market conditions (Wood and Jotzo, 2011). A floor price prevents the permit price to fall below a predetermined threshold, and thereby provides more confidence for investment in low-emissions equipment. It will tend to encourage more investment, because it eliminates the risk that a possibly very low market price for emissions could render low-carbon investments unprofitable.

In a scheme that is not linked to other jurisdictions' permit schemes or offset schemes, a price floor can be implemented by way of a reserve price at auction of permits, which acts to reduce the amount of permits sold into the market, thus retaining the value of existing permits at that level. Implementation is more complex if the aim is to simultaneously import lower-cost international emissions units, but this is unlikely to be relevant in the case of Chinese regional pilot schemes.

A *price ceiling* protects emitters from overly high carbon prices. It is implemented by issuing additional permits at a predetermined threshold price. Upholding a 'hard' price ceiling requires issuing a potentially unlimited amount of extra permits if demand for permits drives the market price to the ceiling. This is how a price ceiling is usually conceived or implemented. The effect is the same as that of a compliance penalty, where emitters are charged a fixed penalty for every unit of emissions that they do not cover with a permit.

It is also possible to implement a 'soft' price ceiling, by issuing a limited number of additional permits at a given threshold price, and let the price rise further if demand is still not satisfied. It is possible to define several steps of price ceilings, with specific amounts of additional permits issued as the price reaches each step. This concept is found in the US Waxman-Markey draft legislation (which was not passed by the US Congress), where it took the shape of an 'allowance reserve', a share of permits set aside from normal permit release and held in reserve to be released if the market price reached a certain level.

International practice

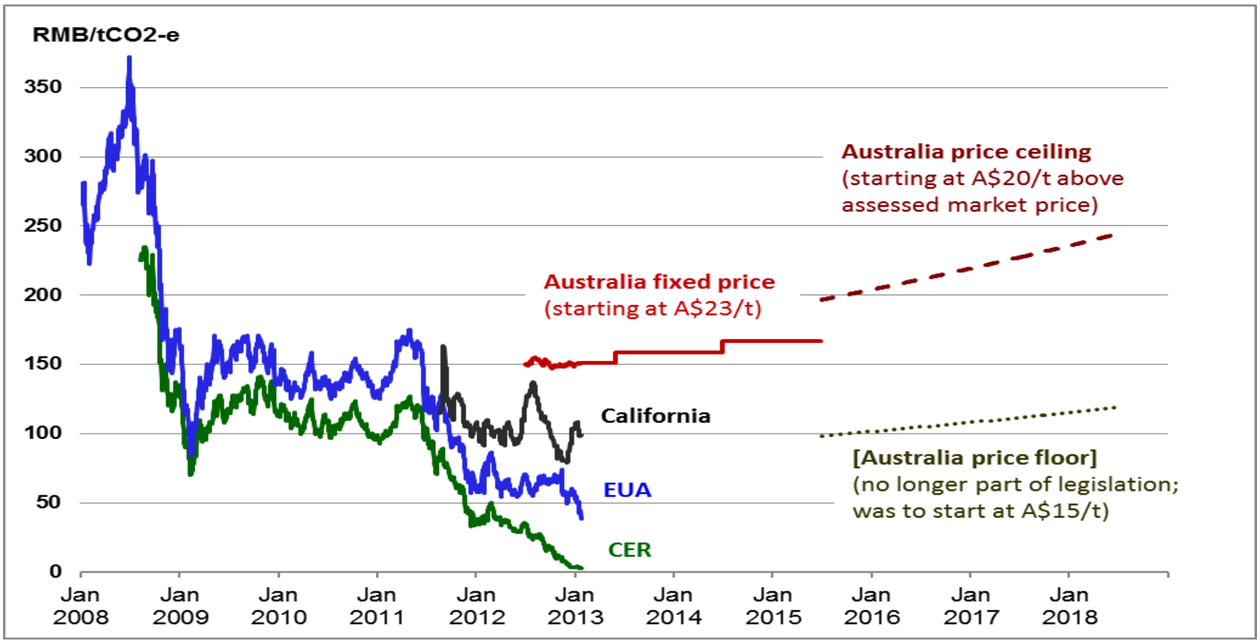
Australia's carbon pricing mechanism was originally legislated to have both a price floor and a price ceiling, during a three-year period after the end of the fixed price (2015 to 2018). The rationale for the price floor is to foster confidence for low-carbon investments and to achieve a minimum level of domestic effort, in the context of open access to international markets for CDM offset credits traded at very low levels (Jotzo and Hatfield-Dodds, 2011). Government proposed to implement the price floor through a variable top-up fee on the use of international emissions units, to bring the effective cost of using low-cost international units up to the floor price scheme (Australian Government, 2012).

The price floor has been replaced with a binding quantitative limit on the use of CDM credits (up to 12.5% of the permit liability of any liable entity), and provisions for linking the Australian scheme with the EU ETS. There is to be one-way linking (Australian emitters allowed to use EU permits) from mid-2015, and two-way linking from 2018.

The rationale for the price ceiling is to eliminate the risk to emitters of unaffordable prices. The price ceiling remains in the Australian scheme, but is thought to be unlikely to apply. The ceiling price is to start at A$20/t above the expected international price for 2015, and rise by 5% real per year.

Carbon price levels in the Australian scheme, compared to EU permit prices, CDM credit prices and Californian ETS prices, are shown in Figure 3.

Carbon market prices and Australia's system of managed prices



Note 1: All prices are in nominal RMB. EUA: EU Emissions Allowances for Dec 2012 delivery (2008-11) and Dec 2013 delivery (2012-13). CER: Certified Emissions Reductions for Dec 2012 delivery (2008-11) and Dec 2013 delivery (2012-13). Price data from PointCarbon. Last data point is 23 January 2013.

Note 2: Historical exchange rate data from Deutsche Bank and Reserve Bank of Australia, assuming 0.1526 A$/RMB for all future dates. Price ceiling assumes an assessed market price of A$10/tCO2 in mid-2015, thus price ceiling starts at A$30/t; rising at 7.5% nominal per year (5% real, assuming 2.5% inflation). Price floor was to start at A$15/t and is shown here rising at 6.5% nominal per year (4% real, assuming 2.5% inflation). The price floor was removed from Australia's Clean Energy Future legislation and replaced with a quantitative limit on CERs and linkage to the EU ETS.

4.5 Price targeting through variable permit supply

The various options for price control discussed above all effectively override predetermined cap on the supply of permits into the market, depending on the permit price:

- A fully flexible amount of permits in the case of a fixed price,
- Fewer permits than the cap to uphold a price floor (unless there are imports of emissions reductions units, in which case the price floor reduces import levels), and
- More permits than under the cap to implement a price ceiling.

Considering hybrid approaches from the starting point of the cap leads to the possibility of price stabilisation by way of adjusting the effective permit cap if prices are unexpectedly high or low (Newell et al., 2005). Rather than determining hard limits for the permit price, a scheme could define an indicative cap for emissions as well as a target price range. The actual supply of permits issued into the market could then be flexibly increased or decreased, in order to keep the price within (or close to) the targeted price range.

Such a system could be implemented using one of two basic approaches:

- A rules-based system of permit supply, where the amount of permits issued for a particular period is increased from the default if the price is higher than some threshold level, and fewer permits are issued if the price is lower than desired; or
- A target price range could be published, and a dedicated (ideally independent) body makes the permit supply decisions in such a way as to target a permit price in the published range. This is the 'carbon central bank' model, similar to inflation targeting by varying money supply as practiced by existing central banks.

International practice

The European Union has been considering measures to delay the issuance of a share of permits slated for release in future years ('set-aside' of permits), thus deviating from the pre-announced EU ETS cap and trajectory. The rationale is to increase the EU permit price, which has plummeted in response to a dimmer economic growth outlook. If implemented, this would amount to varying the cap in response to observed prices.
In Australia, legislation provides for the possibility that the national emissions target for the year 2020 may be changed at a future point in time, and with it the scheme cap in the emissions trading scheme. The Australian Climate Change Authority is to make recommendations to future governments on such adjustments.

4.6 Considerations for China on price management

For a Chinese national ETS, letting the market price float in line with other international markets and long-term price expectations could be desirable in the longer term. This would ensure minimization of divergences in carbon prices, improving the cost-effectiveness of global abatement, and minimizing any distortions in international competitiveness of emissions-intensive industries.

However during the early phases of a national ETS, there is likely to be significant uncertainty over the relationship between emissions caps and permit prices, and potentially high permit price variability. At the same time, opportunities for linking with other countries' schemes could be limited during the early phases of a Chinese trading scheme. This may make it desirable to implement price management mechanisms to retain the carbon price within a "comfort zone".

Carbon price management may be needed as an essential feature of Chinese carbon trading schemes, in particular during the start-up phase, and in pilot trading schemes.

Suitable options for China to achieve these goals is could be (1) a form of hybrid emissions pricing scheme, either by way of a price collar (price floor and ceiling), or by way of flexible supply of permits aimed to keep the price in a pre-defined range; or (2) starting out with a fixed price scheme and shifting to emissions trading if and when conditions are right.

It is possible to shift over time between the different modes of managed and non-managed emissions trading. For example, it may be suitable to start a national scheme as a fixed price permit scheme, in order to provide initial price certainty and gain extra time to develop the necessary systems for nation-wide permit trading. This could then be transformed into a trading scheme with a price floor and price ceiling or trading with variable permit supply. Over time, it may be desirable to gradually phase out the price control elements, for example by widening the price range. Integration in international permit markets may be desirable over time, once markets in other countries have matured and policy uncertainties that currently bedevil schemes in Australia as well as Europe are resolved.

An alternative phased approach would be to start out with a fixed price scheme, and at an appropriate point in time to move directly to fully floating pricing, possibly including trading with international markets when the preconditions are established in other countries.

Price controls may be particularly relevant for China's pilot carbon market schemes and a possible national emissions trading scheme, because the market price is especially difficult to predict for a number of reasons.

- Economic growth tends to be variable both in its speed and its sectoral composition, making it impossible to reliably forecast a 'business-as-usual' emissions trajectory.

- In turn, it is not possible to reliably quantify the emissions reduction task inherent in any given emissions target.
- The cost of achieving abatement using a market-based scheme in China is not yet known. Together with the uncertainty about the abatement task, this translates into significant uncertainty about the cost of achieving any given emissions target, and about the price in a carbon market.
- The price uncertainty is especially strong in new schemes such as the proposed pilot trading schemes, because of a lack of market information; because predictability at the city and province level is likely to be more limited than for China overall; and because of limited information about future policy settings; and because of the possibility of expectations that the duration of the initial phase of the schemes could be limited.
- If the ambition inherent in targets were relatively limited in the initial stages, and if future price expectations are not reflected in early stage prices, then there is a distinct possibility that actual emissions could be lower than the target even with a zero carbon price, as happened in the first phase of the EU ETS. This would make the carbon market inoperative and send a negative signal about its future operation.

On the other hand, if the price is capped, this implies exceeding the emissions cap, with flow-on effects on the national emissions target. This in turn may require stronger mitigation policies in non-covered sectors, and/or purchases of international emissions units. To the extent that either option takes place at higher marginal costs than the regulated emissions price, this may lead to higher overall costs than if the price was free to adjust.

Research needs

Quantitative modelling is needed of the effect that various levels of minimum and maximum prices under a Chinese ETS may have on emissions levels. This is in order to be able to inform decisions about permit price ranges that are likely to allow meeting China's emissions target range of a 40 to 45% reduction in emissions intensity. Research methods are closely related to those for modelling of emissions caps, discussed in Section 5. They comprise CGE modelling, partial sector specific models and projections, and regression-based analysis.

In addition, surveys of experts and potential market participants ahead of the introduction of pilot schemes or a national scheme could be useful in gauging market expectations (Jotzo et al., 2012).

5 Permit allocation and revenue use

Key messages:

- *The decision about permit allocation is separate from the decision about an overall cap for an emissions trading scheme.*

- *Carbon pricing can provide a source of revenue for government, which can be used to channel revenue to assist households with any additional costs, to finance other government spending including support for innovation in low-emissions goods, services and processes, or to lower other taxes. Carbon pricing can thus be seen as fiscal policy reform.*
- *While schemes such as the EU ETS have started out allocating most permits for free to emitters, it will usually be a better option to allocate only a share of permits for free, on the basis of clearly defined rules and where there are good economic reasons for free allocation. The Australian carbon pricing scheme is an example of this approach, as is the third phase of the EU ETS.*
- *Assistance to industry should be provided in a way that does not compromise incentives to reduce emissions. The choice between lump-sum allocation of free permits and output-based allocation needs to be considered carefully. Assistance arrangement should be carefully calibrated, regularly reviewed, and phased out over time wherever appropriate.*

5.1 Revenue from carbon pricing

From an analytic perspective, the question whether and to what extent to allocate carbon revenue back to emitters depends primarily on whether emitters can pass on their increased costs of production (arising from the carbon price) to their consumers. If they can fully pass on their extra costs, then there is no case for free permits, tax exemptions or cash refunds. On the other hand if producers cannot change their product prices at all – for example because they compete directly with producers that are not subject to carbon levies – then there can be a valid economic case for allocating permit revenue back to them (see below on options how to do this).

Existing carbon pricing schemes allocate an increasing share of overall revenue to these purposes, rather than returning the money to emitters. The Australian scheme allocates about half of initial scheme revenue to industry, with the share expected to shrink in future years. The EU is shifting from predominantly free allocation of permits (Phases I and II, 2005 to 2012) to a greater role of auctioning and retaining revenue for member state governments, with around 40% of permits expected to be auctioned in 2013, the first year of Phase III of the EU ETS.

Revenue use

To the extent that net revenue is generated for government (rather than returning revenue to emitters) this can be used in a variety of ways. One classification of the options is the following:

- Finance other climate change mitigation programs;
- Return carbon revenue to households, including through tax reform;
- Use revenue towards the general government budget (no earmarking).

The first option (earmarking for climate change programs, such as subsidies for renewable energy or investments in highly energy efficient equipment) has clear attractions in terms of introducing carbon pricing as part of a package of policies, which overall may be able to be kept revenue neutral. However, it may create fiscal distortions, and unnecessarily link otherwise unrelated policies. For example, if carbon pricing was to be removed or the price to fall, this could cause financing deficits for other programs that are meant to be continued.

The second option (revenue distribution to households) may be called for from an equity perspective, if carbon pricing results in higher prices for energy and goods. In that case, consumers foot the ultimate bill for the economic costs of the carbon emissions policy, and there is a case to compensate them for the increased cost of living.

There are typically prominent distributional considerations as well. Governments usually will want to shelter the poor, as well as low to middle income earners from adverse impacts on their standard of living. Depending on available fiscal instruments, targeted assistance can be provided through taxation, welfare payments or possibly regulated prices for some commodities or services.

The third option (carbon revenue to general budget) is in line with what is generally seen as best fiscal practice. It treats carbon pricing as another source of government revenue, with any decisions about how to use the revenue completely separate. This allows, in principle, to achieve the most efficient or socially optimal use of the carbon pricing revenue. It seems plausible that over time, carbon pricing will be treated as part of the overall fiscal revenue mix.

International practice: Australia's tax reform for household assistance

The Australian scheme is the first large carbon pricing mechanism where a substantial share of the gross revenue is re-allocated to households with the explicit aim of offsetting increased cost of living for lower-income households.

Roughly half of the value of the permits will be given to industry as assistance, and half to households, particularly in the lower to middle income range, during the first few years of the phase (Australian Government, 2011a).

Around A$5 billion per year (on average over the first three years) will be returned to households in the form of lower income taxes and higher welfare payments. Just under half of the household assistance is delivered through increased welfare payments, for example to the elderly without other sources of income, and those who cannot participate in the workforce, and the unemployed, and just over half through changes to the income tax system. As a result, the majority of lower income households will be overcompensated for the increase in living costs that they will experience, even if they do not change their consumption patterns. Households in higher income brackets will bear most of the net costs, as their tax reductions will typically be smaller than their additional costs of living. Targeting household assistance at lower income groups directly tackles the most widespread concern about the scheme, namely increases in the costs of electricity.

For low to middle income earners, there will be a slight increase in the real wage (nominal wage divided by price levels) as the reduction in income taxes outweighs the inflationary effect of the carbon price. This is expected to have positive effects on workforce participation, and thereby offset some of the economic costs of the policy overall (Australian Government, 2011c; Phillips, 2012). In particular, part-time employees in low-wage jobs may find it more attractive to offer their services in the workforce.

Conversely, if household assistance had been provided in the form of lump-sum payments rather than tax cuts, the incentive effect from tax reform would have been lost. In that case, the increased price level in the economy would have led to a decrease in the real wage (even if people would be kept equally well off through assistance payments). Industry also receives substantial payments, as discussed in the following Section.

5.2 Free permit allocation and industry assistance

Early indications are that most Chinese pilot schemes are planning to allocate most or even all of the carbon permit revenue back to emitters (Appendix Table 2). This would typically take the form of giving emissions permits for free to emitters. It can equivalently be done by selling or auctioning all permits, and in return making cash payments to emitters.

For traded products, industry assistance can be understood in the context of limited degree of cost-pass through in markets, because there is competition with producers in cities and provinces that do not impose carbon levies. Provincial or pilot city governments may want to limit or avoid any disadvantage in production costs arising from the carbon pricing scheme relative to producers outside of the boundaries of the scheme. On the other hand, the extent of ‘carbon leakage’ from pilot schemes is likely to be very limited because of the expected transient nature of differential carbon pricing between Provinces and cities.

For electricity generators, this can be understood in the context of existing state-controlled pricing systems that may not allow generators to raise their prices even if they face additional costs. For carbon payments for indirect emissions in electricity, the justification for free permits can be lesser. For example in the building sector, owners of buildings liable for carbon payments for electricity may be able to pass the increased cost on in the form of higher rents.

Grandfathering or lump-sum payments

Carbon revenue can be returned to emitters by way of free permits or cash payments on the basis of historical emissions levels or any other basis that is not linked to emissions or output during the period of the carbon pricing scheme. It provides full incentives for liable entities to reduce emissions, both by reducing emissions intensity and potentially by reducing output. This is because every tonne of emissions reduced means a reduction in production costs equal to the carbon price, while the amount of free permits (or cash assistance) remains the same.

For full effectiveness of the incentives, it requires that payments (or free permits) are allocated even if companies or installations close down, otherwise some highly emissions intensive facilities might continue operating only because of the payments that are received. Provisions need to be made for free permits or payments to new entrants to an industry, in order not to disadvantage them relative to existing emitters.

This model is suitable for industries that can pass their carbon costs on to customers in the form of higher prices. This is typically the case for domestic industries that operate in competitive markets.

However, it must be noted that in these industries, payments will usually not be necessary for economic efficiency, because the industry as a whole does not become less competitive or profitable. Payments will typically be made only for political or distributional reasons, essentially to compensate the owners of carbon intensive assets. If large amounts of free permits are distributed for free, this can lead to windfall profits, as was the case in the first two phases of the EU ETS.

A specific form of ‘historical’ permit allocation that is to be avoided is to link the amount of free permits given in a future year to the level of emissions or production of a facility during a previous year *after* the announcement or start of the scheme. An example is giving out free permits during 2014 amounting to *x*% of actual emissions during 2013. While this may seem in line with the logic of gradual year-to-year emissions reductions, in fact it negates the incentive to reduce emissions. If a company knows that their amount of free permits in 2014 depends directly on the level of emissions in 2013, then they have no incentive to reduce emissions in 2013, because any savings in permit costs during 2013 would be outweighed be getting a smaller allocation in 2014.

To preserve incentives to reduce emissions is important to avoid linking assistance payments or free permits to the level of actual emissions. No major existing carbon pricing scheme provides assistance in this manner. However proposals for assistance to energy users (especially households) are sometimes framed in this way, for example using carbon revenue to subsidise electricity prices for private users back down to the level that would prevail without a carbon price. This would mean that energy consumers have no financial benefit from reducing energy use.

Output-based allocation

Output-based allocation is an option where free permits or payments are linked to the amount of output of a specific product or activity level in a specific process. It provides incentives to reduce emissions intensity of an activity, because the amount of free permits is only dependent on the amount of output, not the amount of emissions; but it provides reduced or no incentives to reduce output. Payments to trade-exposed emissions-intensive industries under the EU ETS (Phase 3) and in Australia use output-based allocation of free permits.

Output-based allocation is suitable in situations where industries cannot pass their increased costs through to the customers, and governments want to counteract changes in competitiveness due to carbon pricing. It retains supply-side incentives to shift to more efficient equipment, lower-emissions processes and lower-carbon energy sources. This is typically the desired result in industries where companies cannot reflect their carbon costs in higher product prices, because they compete with producers in other jurisdictions that do not face comparable constraints or penalties on emissions. Such a system gives an advantage to installations that have relatively high efficiency, and puts low efficiency producers at a disadvantage. It does not, however, discourage the production of the goods in question (or discourages it only to the extent that less than 100% of emissions are covered by free permits).

Benchmarking

In practice, output-based allocation is usually best implemented by way of benchmarks for the output of specific industrial products or specific industrial production activities. For example, *x* free permits may be allocated for each tonne of a particular type of steel produced, where *x* is benchmarked to the average emissions intensity for that production, or to best practice in an industry.

In the EU ETS, the benchmark is calibrated to the 90th percentile of producers ranked by efficiency. In the Australian scheme, benchmarks are calibrated to the industry-wide average emissions intensity of production, and free permits are then allocated for a defined share of the benchmark (94.5% for the most emissions intensive activities, 66% for some other categories of production; both assistance rates are reduced by 1.3% each year). For optimum operation, a fine-grained activity level, rather than output of broad product categories, needs to be used as a basis for allocating free permits.

If rates of free permits given out for each unit of product output (benchmarks) are set at high levels, this can lead to a situation where a producer receives a greater amount of permits for each unit of output of an emissions intensive good than required to cover actual emissions. This amounts to a subsidy to output, giving distortionary incentives to expand production beyond the efficient level. This will have the opposite effect of that desired, namely to increase emissions.

Overly large allocations of free permits can also result in windfall profits. It has been documented that a number of energy intensive industries in the EU significantly increased their profits as a result of getting permits for free, amounting to, on average, nearly the full amount of emissions in preceding years.

Table 2 Models of allocating free permits to emitters

	Grandfathering or lump-sum allocations/payments	**Output-based allocation**
Basis for allocating free permits (or cash assistance payments)	Linked to past emissions or output, or determined on any other basis. May be in form of free permits or cash.	Linked to production levels during the period of the scheme, usually defined as benchmark for an industrial activity
Link to levels of activity during the emissions trading scheme	No link to contemporaneous emissions or output	No link to contemporaneous emissions but link to output
Payments made even if business closes	Yes (if not, then incentives to reduce emissions are distorted)	No
Treatment of new entrants	Needs to be defined separately	Same treatment as existing emitters in same industry
Incentive effect of carbon price	Full incentives to reduce emissions intensity and to reduce output (provided payments made also if facilities close down)	Incentives to reduce emissions intensity, but incentives to reduce output are reduced or eliminated (depending on the rate of assistance)
Examples of applications	Australia’s power sector, EU Phase I and II	Australian and EU Phase III assistance for trade-exposed emissions intensive industries
Caveats on application	Payments will usually not be necessary for economic efficiency, only for political or distributional reasons. High amounts of free permits can lead to windfall profits. Sunset clauses are useful.	High rates of free permits can lead to windfall profits (subsidisation of output), and to incentives to expand production beyond the efficient level. Arrangements should be reviewed over time.

Border tax adjustments

An alternative to output-based allocation is *border tax adjustments*. Under this model, exports of emissions intensive goods receive a rebate for the carbon costs, and imports for are subject to a levy on the embodied carbon emissions. There is then no need for allocating free permits or making payments based on production.

Border tax adjustments can be seen as a theoretically appealing solution to the issue of differential carbon pricing between different jurisdictions, but would typically be difficult to implement both for legal and political reasons, and for practical reasons such as the need to estimate the embodied carbon emissions in imported goods.

A considerable potential problem with border tax adjustment is that they are likely to be even more prone to capture by interest groups than free permits. They could easily be used for protectionist purposes. Even if implemented solely for the purpose of correcting for differentials in carbon costs between countries, there could still be the appearance of discriminatory trade policies justified by environmental policy.

Furthermore, nations may decide against using border tax adjustments because they can be seen as a protectionist measure, and might risk that trading partners implement trade restrictions that go beyond compensating for carbon pricing related changes in competitiveness. This is likely to be a particular concern in China which is heavily engaged in international trading of manufactured goods.

International practice: Australia

In Australia, emissions intensive trade-exposed activities (such as steel making, aluminium smelting and others) will get free permits, benchmarked by product category and linked to levels of output. Benchmarks and outputs are defined at the level of specific industrial activities rather than companies or industries.

The aim is to compensate companies operating in international product markets for losses in competitiveness, while giving these companies incentives for improving efficiency. Free permits are provided for 94.5% of the industry benchmark emissions for high emissions intensive activities, and for 66% of benchmark emissions for some other activities. These rates are to be reduced by 1.3% per year. The arrangements are also subject to periodic review, with Australia's Productivity Commission charged with analysing and reporting whether assistance is needed in light of policy settings in other countries and market conditions.

The empirical case for shielding trade-exposed industries in Australia has been found to be limited (Australian Government, 2008; Clarke and Waschik, 2012; Garnaut, 2008).

Cash and free permits will also flow to the most emissions-intensive coal fired power stations (A$5.5 billion over five years) and coal mines (A$1.3 billion over six years). The cash payments to generators have been criticised for not having an economic basis because there is no threat of carbon leakage to other countries, and for providing financial transfers from consumers to the assets of the most carbon intensive electricity generators. The power sector in Australia can pass through carbon costs to consumers.

International practice: EU

The EU ETS started out with a system of grandfathering almost all permits to existing emitters. Almost all permits were given out for free by EU member states to their emitters during the years 2005-12, which resulted in windfall profits in a range of industries (Sijm et al., 2006).

Starting with Phase III in 2013, a significant share of permits will be auctioned rather than be given away for free. Emissions-intensive trade-exposed activities will get free permits based on output and with activity-specific benchmarks. The power sector in most countries will no longer get free permits. This change will allow member states to retain some of the carbon revenue for their general budgets.

5.3 Considerations for China on revenue use and permit allocation

In establishing ETS, Chinese governments ought to carefully consider the need to provide assistance in the form of free permits to industry, and the alternative of using revenue to assist households or to use revenue from carbon pricing to pay for other programs. Allocating too large a share of permits for free to industry has opportunity costs.

China has a larger influence on world prices of traded energy intensive goods than most other countries, and so the concern about lack of price pass-through in international markets is a lesser one.

Chinese governments may be able to retain a significant and growing share of permit revenue for purposes such as paying for other climate change policy measures and assisting households through tax relief and welfare payments. In the longer term, carbon pricing can be seen as part and parcel of fiscal policy reform.

Where free permits or other forms of assistance are given to industry, the modalities for this should be carefully designed to preserve incentives to reduce emissions. Assistance arrangements should be regularly reviewed, with an expectation to reduce the extent of industry assistance over time.

Research needs

To inform allocation decisions, firstly qualitative analysis is needed of the in-principle issues facing different industries in China – for example to what extent is it expected that there will be price pass-through to end users that will allow emitters to recoup carbon costs, what if any is the risk of inefficient relocation of industry (carbon leakage), and where assistance payments are necessary, what design will achieve efficient outcomes.

Secondly, detailed quantitative modelling is needed to understand the likely nature and magnitudes of distributional impacts on different industries and different types of households.

The modelling undertaken by the Australian Treasury, consisting of a detailed domestic CGE model coupled with household expenditure models, can be a guide to such a modelling effort. In addition, modelling using sector specific partial equilibrium models will be useful, in particular for the electricity sector.

International experience suggests that assistance arrangements including permit allocation could become the area that is most hotly contested in domestic policy formulation. Reliable analysis is needed to facilitate good policy design.

6 Carbon pricing for China's electricity sector

Key messages:

- *The electricity sector should be included in order to maximise opportunities for cost-effective emissions reductions. All major carbon pricing schemes include the power sector through permit liability on electricity generation.*
- *Ideally, carbon pricing is needed both for the supply-side (direct emissions) and demand-side (indirect emissions) in the electricity sector, at the same emissions price.*
- *If there is full cost pass-through in the power sector, then a carbon price on generators achieves both incentives on the supply and demand side. In China this will require energy pricing reform, which would be usefully pursued in parallel with the introduction of carbon pricing.*
- *If power prices are fixed and electricity generation is covered by a carbon price, then generators may need financial assistance. Models for free allocation of permits need to be carefully calibrated to avoid compromising incentives for operations of existing power plants and new investments, and to avoid introducing distortions.*

Electricity production accounts for around half of China's total energy related CO_2 emissions (IEA, 2012), and therefore needs to be included if broad coverage of total emissions and abatement opportunities under carbon pricing is to be achieved. To achieve a full and efficient abatement response, a carbon price signal needs to apply both in electricity generation (supply side) and electricity use (demand side).

A fundamental difficulty for carbon pricing in China's electricity sector is that electricity supply prices are fixed. This means that changes in cost structures for generators are not automatically passed through the system to be reflected in higher prices for electricity, as they are in competitive electricity markets; and that without reform of electricity pricing systems, there is no carbon price signal on the demand side (Howes and Dobes, 2010).

Furthermore, electricity supply side decisions, such as the merit order of supply from individual power stations, are to an extent regulated, which dampens or eliminates the incentive effect of a carbon price to shift supply within the existing fleet of power stations to lower-emissions stations.

The in-principle solution to these obstacles is energy sector reform, with deregulated power pricing and removal of direct regulatory measures for electricity supply. Such reform would ensure that carbon pricing is fully cost effective, and could also harness efficiencies in the energy sector itself.

Ahead of comprehensive energy sector reform, carbon markets and other policy settings may be able to be designed in such a way that they partially compensate for the existing strictures. There are ways to design ETS and adjust regulatory settings that are likely to provide effective incentives for emissions reductions in power supply and demand, while leaving intact the overall operation of the power sector, and related policy objectives.

6.1 Supply-side carbon pricing in the electricity sector

Electricity supply decisions could ultimately be a larger source of emissions savings than the demand side. Analysis for Australia, where coal fired power has a similarly dominant position as in China, has indicated that changes in the sources of power supply are by far the largest source of emissions reductions that a carbon price would trigger over the medium to longer term. Reductions in power demand relative to the baseline would make the relatively larger contributions in the short term, but at much lower levels than the later supply-side reductions. Similar findings have been established for China (Jiang et al 2013).

Early application of carbon pricing in electricity supply is essential for a longer term effective and efficient carbon pricing policy. This is because any additional power sector investment that does not take into account carbon costs represents a sunk cost to the economy a long-term lock-in to higher than efficient carbon emissions.

An effective response to carbon pricing in the power sector entails three aspects:

- A change in investment, with relatively greater investment in lower emissions plants and relatively less investment in new higher-emissions plants. Again, the carbon price would favour lower-emissions options both in the choice between power plants using different fuels and technologies, and in the choice of technology and efficiency of equipment within a class of power station (in particular, favouring higher efficiency coal combustion technologies).

- A change in the dispatch of electricity, with lower-emissions plants moving higher up the merit order, and annual operating hours increasing for low-emissions plants and decreasing for higher-emissions plants. The cost increase is greatest for the highest emitting plants, making them a less financially attractive supply option. Where wholesale power prices are set in spot markets, higher-emissions plants will only be dispatched at times of elevated power demand when the wholesale price rises sufficiently to cover the operating costs, including carbon costs.

- This change in merit order applies both to the choice of plants of different technologies (eg coal, gas, nuclear or hydropower; renewable energy sources without storage such as solar and wind power will supply into the grid whenever they can produce power), as well as within technologies (eg higher efficiency vs lower efficiency coal fired plants).

- A reduction in electricity demand, through as end users face higher electricity prices.

In a system of fixed power prices and regulated (or partly regulated) power dispatch, as is the case in China, the first hurdle to overcome is existing regulations that result in a dispatch order that does not reflect carbon costs.

This could be achieved by imposing a carbon price and abolishing dispatch regulation, or at least opening regulation up to the extent that supply decisions can be made partially as a result of the carbon price signal.

If dispatch regulation is retained, it could be changed to mimic the effects of a carbon price on the merit order of power stations – that is dispatching lower-emissions plants first, to the extent that their imputed carbon price advantage makes them the lower cost option. This would not in fact require the imposition of a carbon price on the generators, but would require regulations that act "as if" a carbon price was in place.

Imposing a carbon price on generators without raising electricity supply prices means that the profitability of fossil fuel based generators will decrease (or their losses increase) broadly in line with their carbon intensity, and the profitability of the power sector overall decreases by the extent of the overall cost of the emissions liability. In deregulated, competitive power markets, no loss in overall profitability of the industry occurs, as the carbon costs will be recouped from consumers through higher power prices. However the relative profitability of different technologies will be changed, giving the desired incentive effects both for dispatch and investment.

Carbon pricing with fixed power prices

Under a system of fixed power prices, as currently exists in China, the economic viability of power generating assets can be maintained by increasing regulated power prices, or by allocating free permits to generators based on the amount of power they produce. A mixed approach would also be possible.

The first option is to require generators to buy emissions permits and to increase power supply prices, so that the overall increase in revenue is equal to the total cost of emissions permits used by the power sector. No free permits need to be given to generators, and the revenue from permit sales is available to government. Nevertheless, the generating industry as a whole would be kept roughly profit neutral.

This approach covers both the supply and demand side, through the carbon price and the increase in power prices respectively. A potentially important difference to a fully market-based system is that the average power price applies at all times of the year (unless regulation differs), which is likely to introduce some distortions to the merit order with regard to emissions intensity. Furthermore, implementation may be possible only as an approximation: in an ETS with a floating price it will not be possible to exactly match the increase in power prices to the cost of permits, and frequent re-calibration of the regulated power price may be undesirable. Of course, the increase in power prices itself may be politically undesirable, but would be necessary to achieve an effective overall mitigation response.

If power prices were to remain unchanged and carbon pricing for generators introduced, and if there was a valid concern about generators' profitability, then free allocation of emissions permits to generators may need to be considered.

One option is to allocate lump sum amounts of free permits, allowing differential treatment of different power producers (IEA and ERI, 2012). This was done for example in Australia, giving lump sum payments to only the most emissions intensive power generating plants. Although described in terms of securing energy supply, this can be seen as a negotiated settlement with influential asset owners, arising out of political necessity.

A major difficulty with the lump sum approach is the treatment of new entrants. A number of permits can be set aside for new installations. However it is difficult to anticipate how many new generators of what type will come on stream, especially in a fast growing power sector like China's. Hence the new entrants' reserve may need to be very large, or the rules may need to be changed along the way if there is a risk that not enough permits are available; both options have obvious drawbacks.

An alternative is output-based allocations: each generator gets issued a defined number of permits for each unit of power produced. In this model, for full effectiveness it is important to include all generators under the permit liability, and provide free permits equally to all producers – even nuclear and renewable plants which will sell their permits to other emitters.

Output-based allocation of free permits provides the electricity generating industry as a whole with full incentives to reduce emissions intensity of electricity supply. It provides the correct incentives for the dispatch order, because lower emissions plants have lower carbon costs while getting the same amount of permits for free; and also for investments, as lower emissions plants will be relatively more profitable. Furthermore under this method, there is no artificial discrimination between different technologies, individual generators, or between existing plants and new entrants, as is inevitably the case with other methods of free allocation.

However, if using output-based allocation with a common benchmark across all technologies, it may be that in order to achieve levels of assistance payments that are deemed adequate for highly emissions intensive generators, overly large amounts of free permits would have to be allocated across the power sector as a whole.

6.2 Demand-side carbon pricing (coverage of indirect emissions)

The demand side of the power sector can be included through separate coverage with a carbon price of electricity users. Carbon pricing on “indirect emissions”, that is emissions embodied in electricity, could be a complement to demand-side carbon pricing that does not by itself raise power prices. If a carbon price is established separately on the electricity supply and demand side, then in order to promote cost effectiveness, the carbon price in both should be the same, ideally by allowing permits to be tradable between both (Li and Zhang, 2012).

Alternatively, it could be a way to support energy efficiency in end use even if there is no effective carbon pricing on power supply. Most of China’s pilot schemes are planning to put a carbon price on electricity use.

Upstream vs downstream coverage

Indirect emissions from electricity use could be covered in an ETS through either upstream coverage, imposing a carbon levy on all electricity sales within the pilot scheme, or placing distributors of electricity under a permit liability; or by downstream coverage, imposing a permit liability on large users of electricity within the scheme.

In either case, an average emissions factor (eg in tCO2 per Mwh) would be applied to all electricity sales or use. This could be calibrated to be in line with the average carbon intensity of electricity supply.

Under upstream coverage, all indirect emissions from electricity use within a pilot scheme could be covered. At its simplest, this could take the form of a carbon levy on all electricity sales. This however would not achieve the objectives of deepening the carbon market and creating experiences in trading permits.

The alternative for achieving upstream coverage is to place a permit liability on electricity distributors, equal to the amount of emissions inherent in the electricity they sell to their consumers. Under this model there would typically be only a small number of liable entities, but all forms of electricity use would be covered. From the point of view of cost-effectiveness and broad inclusion, this may be the preferable option. However, it would require that power distributors were allowed to raise supply prices to cover their carbon costs.

Under downstream coverage, a permit liability would be placed on large users of electricity. This can only cover a share of indirect electricity emissions, as small electricity users would be excluded.

Depending on the cut-off point for inclusion in the scheme (which could for example be framed in terms of the amount of electricity used per year, or the inherent carbon emissions liability), there will either be a relatively small number of liable entities and relatively smaller coverage, or a larger number and larger share. Transaction costs increase with the number of entities covered, and for small facilities may outweigh efficiency gains. There will be distortions in incentives, as only 'large' facilities are covered and have the additional incentive to reduce their electricity use.

Table 3 Upstream and downstream coverage of indirect electricity emissions

	Upstream coverage	*Downstream coverage*
Implementation	Electricity distributors under permit liability, or levy on electricity sales	Large electricity users under permit liability
Coverage	100% of electricity use	Only a share of electricity use
Cost-effectiveness	Highly cost-effective: small number of direct participants, no distortions	Less cost-effective: large number of direct participants and consequently higher transaction costs, distortions because of partial coverage
Specific requirements	Letting electricity prices increase, either by allowing distributors to charge more, or through a levy on top of the mandated price	Participation of a large number of facilities in trading and permit allocation arrangements

The Tokyo metropolitan emissions trading scheme covers electricity use downstream, by including major electricity users with direct permit liability (Nishida and Hua, 2011). It started its mandatory phase in 2010 covering 1,300 facilities, of which 1,159 individual facilities reported emissions in its first year (970 commercial and service buildings and 189 large scale industrial facilities) which together account for 40% of total city commercial and industrial sector emissions. The scheme covers all facilities using more than 1,500 kiloliters of oil equivalent in their fuels, heat and electricity.

6.3 Special considerations for pilot schemes

A complicating factor for the pilot schemes is that they are linked into grids that are supplied in large part by electricity generators located outside of each scheme. All of the five pilot cities are net importers of electricity, Beijing being most import-dependent with an import share of more than two thirds (see Appendix Table 1).

To also achieve supply side incentives, firstly a permit liability would need to be placed on electricity generators within the scheme, in line with their actual emissions levels. This creates incentives to shift to cleaner fuels and higher efficiency power stations within the scheme.

However if this was implemented by itself and only within each scheme, then generators within the jurisdiction would be at a disadvantage compared to generators outside the scheme exporting electricity to within the scheme. Therefore, "imports" of electricity to the pilot scheme need to be subject to carbon pricing also.

Ideally, the carbon levy on imported electricity should also be calibrated to the emissions intensity of the plants generating the electricity. Thus, importers of electricity would need to pay higher carbon costs if they source electricity from high-emissions plants, and no carbon penalty for electricity from renewable or nuclear plants. They would thus prefer low-emissions sources of electricity.

However, differentiating by emissions intensity of plant would generally only be possible if power is supplied to within a pilot scheme from specific identifiable plants. It would not be possible if the power is drawn from a grid, without specific supply contracts, because it is then not possible to identify the sources of electricity supply. In that case, an average emissions factor could be applied to all electricity imports, for example calibrated to the average emissions intensity of power supplied to the grid.

The carbon liability would need to apply to the utilities that draw power from grid and distribute it, and to any large industrial users that may have direct arrangements for being supplied with electricity generated outside of the pilot scheme’s jurisdiction.

6.4 Considerations for China

Including the electricity sector in China’s ETS, especially in a future national scheme, is possibly the greatest challenge for market-based climate change mitigation in China. Inclusion of the power sector presents unusually complex challenges for mechanism design and policy implementation in the context of existing regulatory structures in the energy sector. It may also meet resistance from established economic interests. Nevertheless, inclusion is essential for the effective and cost-efficient operation of a carbon pricing scheme, and it is possible.

The overarching issue for the Chinese government to consider is a wholesale reform of the regulatory system governing the electricity sector, freeing up both power pricing and regulations for power dispatch. This is generally seen as a larger and longer term challenge than the introduction of a carbon price.

Carbon pricing can be made effective in the presence of regulated electricity prices. A promising option to consider on the supply side is full coverage of all power stations under an ETS, with permits allocated freely on the basis of the amount of electricity supplied.
If there is no increase in supply prices as a result of carbon pricing on the supply side – or if there is no supply side carbon pricing – then electricity use can nevertheless be included on the basis of “indirect emissions”. The option considered by several pilot schemes is to include large users of electricity with a permit obligation. However, such a “downstream” model misses out on a large share of overall power use, unless a very large amount of very small users are included which would be overly costly and impractical.

Research needs

To inform policy decisions about carbon pricing in China's power sector, quantitative analysis is needed of system-wide responses to different modes of carbon prices and related changes in regulations.

For such modelling to be of maximum use, it will need to include a reasonable representation of regulatory and pricing policies in China's power sector. This in turn will require a model that goes well beyond the extent of detail that is represented in standard CGE models. Nevertheless, CGE analysis will be useful to gauge economic flow-on effects of changes in the power sector, including effects that emanate from changes in power prices and electricity sector investments.

In addition to the quantitative modelling, qualitative work is needed to thoroughly understand the effects that various possibly changes in power pricing and regulatory structures will have, by themselves and in combination with various forms of carbon pricing.

7 Conclusions

A national emissions trading scheme for China offers very large opportunities for cost-effective climate change mitigation. The anticipated adoption of market based policy instruments for emissions control is significant, in a fast-growing economy where climate change mitigation policy has been predominantly by command and control approaches, and where many aspects of energy pricing are heavily regulated. The introduction of carbon pricing could also be a catalyst for further market reform, in particular in China's energy and electricity sectors. China has the opportunity to move to world's best practice on carbon pricing. However it faces challenges due to the unique regulatory and institutional environment.

This paper examines a range of policy design issues for a national emissions trading scheme in China, drawing on economic principle and international experience particularly in Australia and the European Union. It finds that

- Broad coverage of carbon pricing can improve cost effectiveness. Not all emitters need to be included directly in emissions trading. Upstream permit liability and equivalent emissions charges or taxes may allow increasing coverage while minimising transaction costs and administrative complexity.
- Translating the national intensity target into an absolute cap on emissions permits presents special challenges because of China's dynamic growth. The framing of the national target in emissions intensity terms may require periodic adjustment of absolute caps in a trading scheme.
- A floating market price float in line with emissions markets in other countries could be desirable in the longer term. In the early phases of emissions trading however there is a strong case for price management.

- This could be achieved through a fixed price model, price floor and ceiling, or variable permit supply. If price controls are enacted, then a phased approach may be appropriate, possibly starting with a fixed price and moving to internationally integrated trading at an appropriate time.
- Provision of assistance to industry in the form of free permits to industry needs to be carefully calibrated, in view of the opportunity costs and risk of lock-in of assistance arrangements. Current international best practice is for governments to retain a substantial share of the overall value of emissions permits to support households, reduce other taxes or finance other policy measures. Where free permits and other assistance is given to industry, the modalities should be carefully designed to preserve incentives to reduce emissions. Built-in provisions for review and phase-out of industry assistance are advisable.
- Establishing an effective carbon price in the electricity sector is possibly the greatest challenge for market-based climate change mitigation in China. It is necessary for an overall cost-effective response, but presents complex issues for mechanism design and policy implementation in the context of existing regulatory structures in the energy sector. Ultimately, market-based energy pricing is needed. However, there are ways to make carbon pricing at least partly effective ahead of comprehensive energy sector reform.
- In-depth qualitative and quantitative research will be needed over coming years. The payoffs from applied research in this area could be very large. If China succeeds in establishing an effective, efficient and robust emissions pricing scheme, this could have a strong demonstration effect for the world, and encourage other countries to emulate the experience.

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Appendix: Data and overview of pilot schemes

Statistics for pilot provinces and cities, and national, 2010

	Pop'n (million)	GDP (RMB billion)	GDP per capita (RMB 1000's)	Energy use (million tonnes SCE)	Energy use per capita (tonnes SCE/ person)	Carbon dioxide emission (million tonnes)	Emissions per capita tonnes CO2/ person/year	Emissions intensity (kg CO2/ RMB)	Electricity use (Gwh)	Electricity imports (-) or exports (+) (Gwh)
Shenzhen SEZ	10	903	87	49	4.7	n.a.	n.a.	n.a.	69	-11
Beijing	20	1182	60	70	3.5	103	5.2	87	83	-56
Tianjin	13	781	60	68	5.3	134	10.3	172	68	-11
Shanghai	23	1556	68	112	4.9	211	9.2	136	130	-35
Chongqing	29	616	21	79	2.7	125	4.3	203	63	-14
Hubei	57	1250	22	151	2.6	320	5.6	256	142	60
Guangdong	104	4016	39	269	2.6	444	4.3	110	406	-86
China	1341	31234	23	3895	2.9	8146	6.1	261	4193	Na
Pilot schemes combined	256	10303	40	798	3.5	1337	5.2	130	960	-142
Pilot schemes share of national total	19%	33%		20%		16%			23%	

Data source: State Information Centre, China Statistical Yearbooks; (Guan et al., 2012) for emissions data (emissions data are not published as part official Chinese statistics). SCE stand for standard coal equivalent.

Overview of key features of pilot emissions trading schemes (as announced by March 2013)

	Beijing	Tianjin	Shanghai	Hubei	Guangdong	Chongqing	Shenzhen
Threshold for inclusion	10,000 tonnes CO2 p/a. This threshold may change to 5,000 tonnes CO2 p.a. if more than 600 companies are chosen (41sectors).	20,000 tonnes CO2 p/a	20,000 tonnes for industrial sectors; 10,000 tonnes CO2 p/a for non-industrial sectors	120,000 tonnes CO2 p/a (60,000 tonnes p/a standard coal equivalent)	20,000 tonnes CO2 p/a	20,000 tonnes for industrial sectors; 10,000 tonnes CO2 p/a for non-industrial sectors	20,000 tonnes CO2 p/a originally planned (100 of Shenzhen's largest companies) This threshold will be changed to below 10,000 tonnes CO2 p/a
Coverage	Initial plan was 400 – 600 companies, but from 2013 likely that coverage will be over 600 firms (of which 340-350 have been selected to trade). These incl. power & heating, bldg. materials, steel & metal processing, oil refining, chemicals, chem. fibre, food, large public bldgs, & services/ transport	120 large companies Industrial firms cover 40% of carbon emissions in the city. These include all top energy users, incl power, steel, oil & gas, chemicals, petrochemicals, cement, non-Fe metals, metal processing, & large public bldgs	197 companies or just over 50% of all emissions. 16 industrial sectors (over 20,000 tonnes p/a), incl power, steel, : Non-industrial & services sectors (over 10,000 tonnes p/a), incl large public bldgs, aviation & harbour services	153 large enterprises (power, iron & steel, chemicals, cement, glass, automobiles, aluminium, food processing). The first 4 are responsible for 90% of provincial emissions.	827 companies in 9 industrial sectors are planned (power, cement, steel, textiles, petrochemicals, ceramics, non-Fe metals, plastics, & paper). This number covers 42% of emissions. Power sector includes 8 "cross-border" Shenzhen power stations. 310 companies will participate in Phase 1 of trading.	The six high-emitting industry sectors include steel, aluminium, chemicals, cement, and non-ferrous metals	Over 800 firms in 9 sectors & 26 industries (54% of emissions) incl. the services sector & large buildings, were initially planned. However, it is likely only 200-300 firms will actually be involved in ETS trading

Electricity sector	Direct and indirect emissions.	Undecided	Direct and indirect emissions.	Direct emissions only	Direct emissions only.	Unknown; possibly direct emissions only	Direct and indirect emissions.
Cap setting	Quotas allocated according to the previous year's emission levels. Caps to be set based on 2005-10 emissions and projections for 2015 and 2020.	Baselines to be set by group of experts.	Quotas based on 2009-11 emissions considering context, expected growth and previous abatement. Caps for 2013-2015 allocated at once.	Based on historical emissions. Mechanism to be set by group of experts.	Based on 2010-2012 emissions and characteristics of each industry. 2013-2015 quotas allocated at once. Reviewed annually by GD DRC.	Unknown	Mechanism still under discussion. Baselines to be set by group of experts.
Permit Allocation	Large proportion of free permits through grandfathering.	Grandfathering likely for most industries. May be some auctioning, and benchmarking for industries with sufficient data.	Mostly grandfathered. Benchmarking for sectors with clear data. Aiming for timely introduction of auctioning.	Still under discussion. Likely to feature high level of free allocation through grandfathering.	Large proportion of free permits through grandfathering.	Unknown	Starting with a large proportion of free permits (some auctioning), reducing over time.
Price stabilization	Safety valve: government auction and buy-back of quotas.	Safety valve likely, government auction and buy-back of quotas.	Not officially disclosed.	Not yet decided.	Not officially disclosed.	Unknown	Not officially disclosed.

Sources: Thomson Reuters; China Beijing Environment Exchange; Tianjin Climate Exchange; Shenzhen Emissions Exchange; Provincial People's Government of Guangdong; Municipal People's Government of Shenzhen, and Tsinghua, Fudan, Wuhan and Universities. In some instances information is from personal communications with relevant officials and researchers.

Part 3: Modelling emissions trading schemes: Australia's experience and China's studies

(1) Insurance against catastrophic climate change: How much will an emissions trading scheme cost Australia?[7]

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Abstract

There is now compelling advice from the scientific community that a sharp cut in world green house gas emissions would substantially reduce the risk of catastrophic climate change over the next century. Cutting greenhouse gas emissions is like buying an insurance policy: we incur a cost (a loss in GDP) to reduce a risk (catastrophic climate change). In any insurance decision, the cost matters. If a worthwhile reduction in risk costs 50 per cent of income, then living with the risk may be preferable. But if it costs 1 per cent of income, then taking the insurance policy may be the best option.

The purpose of this research paper is to evaluate the possible cost in the context of an emissions trading scheme (ETS) for Australia, consistent with that established in July 2012 as part of the Australian government's *Clean Energy Plan* (www.cleanenergyfuture.gov.au/clean-energy-future/our-plan/). The analysis is based on simulations of the Monash Multi-Regional Forecasting (MMRF) model. The Australian carbon price framework is assumed to be part of a global ETS. Over time, the global ETS becomes the dominant greenhouse abatement policy for all countries including Australia. It sets the price for carbon permits and allocates the number of permits available to each country.

A number of key findings emerge from the MMRF simulations of the effects of the ETS policy in Australia:

1. Domestic abatement efforts fall well short of targeted abatement (5 per cent below 2000 levels by 2020 and 80 per cent below 2000 levels by 2050), requiring significant amounts of emissions permits to be purchased abroad.
2. Despite the requirement for deep cuts in emissions, the ETS reduces Australia's GDP by 1.1 per cent relative to the base-case level by 2030. To put this into context, in the base case real GDP grows at an average annual rate of 2.60 per cent between 2010 and 2030. With the ETS imposed, average annual growth falls to 2.55 per cent.

[7] This is a highly abridged version of: Philip D. Adams and Brian R. Parmenter (2013), "Computable General Equilibrium Modelling of Environmental issues in Australia: Economic Impacts of an Emissions Trading Scheme", Chapter 9 in P.B. Dixon and D. Jorgenson (eds) *Handbook of CGE Modelling*, Vol. 1, Elsevier B.V.

3. The negative impact on real household consumption (the preferred measure of national welfare) is a little higher (1.7 per cent relative to its base-case level in 2030), reflecting the need to import permits. International trading in emissions units is therefore important for Australia.

4. The national macroeconomic impact of the ETS is described as **very small** in the context of the policy task.

5. However, the very small overall economic impact does not carry through to the industry and state/territory levels, where some industries and regions were particularly vulnerable. Good examples are coal-fired power generation and the aluminium smelting industry, and their associated regions. In these cases the government might consider, in the short-term, compensation through free-allocation of permits, and in the long-term, adjustment programs focusing on re-training and the establishment of new less emission-intensive industries.

The need for detail, and the need for a suite of models, international, national and sectoral/ regional, is highlighted throughout the analysis. For example, a suitably detailed treatment of electricity supply is provided by linking CoPS' model with *Frontier Economic's* detailed bottom-up model of the stationary energy sector. Similarly, necessary detail on the effects of the global ETS on Australia's international trading conditions is provided by linking with a multi-country model.

Introduction

The key distinguishing characteristic of Computable General Equilibrium (CGE) modeling in Australia is its orientation to providing inputs to the policy-formation process. This reflects the history of the funding of CGE research. Australia's best known CGE modeling group - the team now located in the Centre of Policy Studies (CoPS) at Monash University - was originally established in 1975 by the Australian Government under an inter-agency arrangement – the IMPACT Project – administered by the (then) Industry Commission (now the Productivity Commission). Since then, Australian government departments, principally the Productivity Commission and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), have continued to support CGE research and have maintained substantial in-house modeling capabilities. Universities, principally Monash University, have played an important role in the development of CGE models in Australia but the focus of the work has always been as much on practical application of the models as on contributing to the academic literature.

Policy makers require detail. They want to be able to identify convincingly which industries, which occupations, which regions and which households would benefit or lose from policy changes, and when the benefits or losses might be expected to flow. Economic theory alone, or stylized general-equilibrium analysis, is not well suited to meeting information demands at this level of detail.

But combining the theory in a CGE framework with disaggregated input-output data, labor-force survey statistics, data on the sector composition of the regional economies, and household income and expenditure data provides the tool that policy makers require.

Starting in the early 1990s, greenhouse-gas emissions, global warming and climate change emerged as prime policy concerns in Australia, culminating in 2007 with the Australian government's decision to ratify the Kyoto Protocol and to attempt to introduce a greenhouse-gas emissions trading scheme. CGE modeling has played a prominent role in informing Australia's emissions-policy debate.[8]

As in earlier policy debates (about trade liberalization, for example), detail has been a key issue for economic modelers engaged in the emissions debate. In this context, modelers face a number of questions relating to model, data and simulation design.

- Stationary energy accounts for more than 50 per cent of Australia's greenhouse-gas emissions. At what level of detail must the stationary-energy sector be modeled for the effects of policy on its emissions to be captured adequately? And is the required level of detail better provided by augmenting the representation of the sector inside the CGE model or by linking the CGE model with a detailed bottom-up model of the stationary energy sector?
- Investment in electricity generation (and many other branches of heavy industry, including energy-intensive minerals processing) is typically lumpy, not smooth. Is it necessary to include this lumpiness explicitly in CGE computations of the effects of climate-change policy? To what aspects of the results does lumpiness matter?
- Concern about greenhouse-gas emissions centers on a global externality problem. Does this mean that the consequences of emissions policy can only be investigated using a global model? In any case, the domestic effects of a particular country's policy will depend on what other countries do. If a single-country model is used to analyze the domestic policy effects, how can the effects of foreign countries' policies be included?
- Emissions policy is policy for the long term, with the underlying global externality and many abatement options involving complex dynamics. It is now common for CGE models to have dynamic or quasi-dynamic structures but what dynamic mechanisms are required to make a meaningful input to decisions about emissions policy? For example, do we need agents with full inter-temporal optimization or will recursive dynamics do?
- The possibility of international emissions leakage is a problem that proponents of unilateral emissions policy must face. What representation of a country's emissions-intensive trade-exposed industries is required to handle this?

[8] Academic contributions started with Dixon *et al.* (1990) and Dixon and Johnson (1993), followed by McDougall and Dixon (1996) and McKibbin and Pearce (1996).

- The energy consumption of end users (including households) is conditioned by their investment decisions about energy-using equipment (appliances, vehicles etc.) – another aspect of the dynamics of emissions policy. National accounts based models do not handle this well as far as households are concerned. How should energy usage be treated in the household-consumption specification of a model to be used for the analysis of emissions policy?
- Emissions-intensive industries, especially in the energy sector, tend to be geographically concentrated, due mainly to the availability of primary energy sources - fossil or renewable. Hence, emissions policy could have significant regional effects. How can policy models inform policy makers about such effects?
- Carbon taxes and most emissions-trading schemes would raise large amounts of government revenue and increase consumer prices. What effect will the recycling of this revenue have on the efficiency costs of the policy and on income distribution? To deal adequately with these issues, a policy model will need a detailed representation of the country's fiscal system and the ability to identify the income-distribution consequences of policy options.

In this paper, how these issues have been handled by Australian CGE modelers is explained. This is done using an example: the analysis of the potential impacts on the Australian economy of a carbon-price policy outlined in the Government's *Carbon Pollution Reduction Scheme Green Paper* (Department of Climate Change, 2008; Department of Treasury, 2008) and the Garnaut Climate Change Review (Garnaut, 2008). The policy is assumed to apply as part of a global Emissions Trading Scheme (ETS). Over time, the global ETS becomes the dominant emissions-abatement policy for all countries, including Australia. It sets the price for carbon permits and allocates the number of permits available to each country.

The analysis relies on a series of applications of three CGE models developed in Australia: the Global Trade and Environment Model (GTEM) (Pant, 2007); the G-Cubed model (McKibbin and Wilcoxen, 1998); and the Monash Multi-Regional Forecasting model (MMRF) (Adams *et al.,* 2011).[9] GTEM and G-Cubed are multi-country models. MMRF is a single-country multi-regional model of Australia and its six states and two territories.

Much of the modeling of the global aspects of the ETS was undertaken using the GTEM model. Information from GTEM was then used to inform simulations of MMRF.[10]

[9] MMRF and GTEM are solved using GEMPACK software (Harrison and Pearson, 1996). An overview of the current version of GEMPACK is given in Harrison and Pearson (2002).

[10] G-Cubed was broadly calibrated to the GTEM base case scenario, and provided comparative global cost estimates for the policy scenarios based on different rate-of-adjustment assumptions for global capital markets.

The role of MMRF was to supply estimates of the effects of the scheme on the Australian economy at the level of detail required by the policy makers. A key dimension was detail about the electricity system. To cover this, MMRF was linked to a specialized bottom-up model of the Australian electricity system. In the original work commissioned by the Treasury and the Garnaut Review, the electricity modeling was conducted by the consulting firm McLennan, Magasanik and Associates (MMA), using their probabilistic simulation model of the electricity market.[11] Subsequent studies were undertaken with the consulting firm Frontier Economics, using Frontier's *WHIRLYGIG* model of electricity supply (Frontier Economics, 2009). The latter studies also contained updated base-case assumptions and updated views about growth of Australia's trading partners with and without a global ETS. The results discussed in this Paper are from these latter simulations.

The rest of the paper is organized as follows. A brief general description of MMRF is given in Section 2. In Section 3 the enhancements of the general form of the model that were necessary for the ETS modeling are described. Specific items discussed are:

- linking with GTEM and with the detailed electricity model;
- modeling the free allocation of permits to shield emissions-intensive, trade exposed industries during the period of transition to a full global ETS;
- modeling abatement of non-combustion emissions in response to an emissions price; and
- land-land substitution in agriculture and forestry.

Aspects of simulation design are given in Section 4 (the base case) and Section 5 (the policy simulation), including the exogenous shocks that drive the policy simulations. The effects of the shocks are given in Section 6 as deviations between the values of variables in the policy simulation and their values in the base case. Concluding remarks are in Section 7.

MMRF

Overview

MMRF is a dynamic, multi-sector, multi-region model of Australia. The current version of the model distinguishes 58 industries (Table 1), 63 products produced by the 58 industries, 8 states/territories and 56 sub-state regions. At the state/territory level, it is a fully-specified bottom-up system of interacting regional economies. A top-down approach is used to estimate the effects of the policy at the sub-state level.

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[11] An overview of MMA's suite of models covering the National Electricity Market (NEM), South West Interconnected System (SWIS) and the Darwin Katherine Interconnected System (DKIS) is given in MMA (2008).

Of the 58 industries, three produce primary fuels (coal, oil and gas), one produces refined fuel (petroleum products), six generate electricity and one supplies electricity to final customers. The six generation industries are defined according to primary source of fuel: *Electricity-coal* includes all coal-fired generation technologies; *Electricity-gas* includes all plants using turbines, cogeneration and combined cycle technologies driven by burning gas; *Electricity-oil products* covers all liquid-fuel generators; *Electricity-hydro* covers hydro generation; and *Electricity-other* covers the remaining forms of renewable generation from biomass, biogas, wind etc. Nuclear power generation is not currently used in Australia but *Electricity-nuclear* is included and could be triggered, if desired, at a specified emissions price.

Apart from *Grains* (industry 4) and *Petroleum products* (industry 20), industries produce single products. *Grains* produces grains for animal and human consumption and biofuel used as feedstock by *Petroleum products*. *Petroleum products* produces gasoline (including gasoline-based biofuel blends), diesel (including diesel-based biofuel blends), LPG, aviation fuel, and other refinery products (mainly heating oil).

Environmental enhancements

In this sub-section, the key environmental enhancements of MMRF to facilitate the ETS study are described. These are:

- an accounting module for energy and greenhouse-gas emissions that covers each emitting agent, fuel and region recognized in the model;
- quantity-specific carbon taxes or prices;
- equations for inter-fuel substitution in transport and stationary energy;
- a representation of Australia's National Electricity Market (NEM); and
- an improved treatment of energy-using equipment in private household demand.

Energy and emissions accounting

MMRF tracks emissions of greenhouse gases according to: emitting agent (58 industries and the household sector); emitting state or territory (8); and emitting activity (9). Most of the emitting activities are the burning of fuels (coal, natural gas and five types of petroleum products). A residual category, named *Activity*, covers non-combustion emissions such as emissions from mines and agricultural emissions not arising from fuel burning. *Activity* emissions are assumed to be proportional to the level of activity in the relevant industries (animal-related agriculture, gas mining, cement manufacture, etc.).

The resulting 59 × 8 × 9 array of emissions is designed to include all emissions except those arising from land clearing. Emissions are measured in terms of carbon-dioxide equivalents, $C0_2$-e.

Table 2 summarizes MMRF's emission data for the starting year of the simulations – the financial year 2006. Note that MMRF accounts for domestic emissions only; emissions from combustion of Australian coal exports, say, are not included, but fugitive emissions from the mining of the coal are included.

According to Table 2, the burning of coal, gas and refinery products account for around 38, 10 and 23 per cent of Australia's total greenhouse emissions. The residual, about 29 per cent, comes from non-combustion sources. The largest emitting industry is electricity generation, which contributes around 39 per cent of total emissions. The next largest is animal-agriculture, which contributes 14 per cent; agriculture in total contributes nearly 20 per cent. Other large emitters are: transport (including private transport services), with about 10 per cent of total emissions; coal mining with around 5 per cent; and other services (including waste dumps) with nearly 4 per cent.

Carbon taxes and prices

MMRF treats the ETS price on emissions as a specific tax on emissions of CO_2-e. On emissions from fuel combustion, the tax is imposed as a sales tax on the use of fuel. On *Activity* emissions, it is imposed as a tax on production of the relevant industries.

Inter-fuel substitution

In the standard specification of MMRF, there is no price-responsive substitution between composite units of commodities, or between composite commodities and the composite of primary factors.[12] With fuel-fuel and fuel-factor substitution ruled out, $C0_2$-e taxes could induce abatement only through activity effects.

We correct this in two ways:

- first, by introducing inter-fuel substitution in electricity generation using the "technology bundle" approach[13]; and
- second, by introducing a weak form of input substitution in sectors other than electricity generation to mimic "KLEM substitution"[14].

Electricity-generating industries are distinguished based on the type of fuel used (Table 1). There is also an end-use supplier (*Electricity supply*) in each state and territory and a single

[12] Composite commodities are CES aggregations of domestic and imported products with the same name. The composite of primary factors is a CES aggregation of labor, capital and land inputs.

[13] The technology bundle approach has its origins in the work done at the Centre of Policy Studies, Monash University in the early 1990s (McDougall, 1993) and at ABARES for the MEGABARE model (Hinchy and Hanslow, 1996).

[14] KLEM substitution allows for substitution between capital (K), labor (L), energy (E) and materials (M) for each sector: see Hudson and Jorgenson (1974), and Berndt and Wood (1975). Other substitution schemes used in Australian models are described in Paper 4 of Pezzy and Lambie (2001). A more general current overview is in Stern (2011).

dummy industry (*NEM*) covering the six regions that are included in Australia's National Electricity Market (New South Wales, Victoria, Queensland, South Australia the Australian Capital Territory and Tasmania). Electricity flows to the local end-use supplier either directly in the case of Western Australia and the Northern Territory or *via NEM* in the remaining regions.

Purchasers of electricity from the generation industries (*NEM* in NEM regions or the *Electricity supply* industries in the non-NEM regions) can substitute between the different generation technologies in response to changes in generation costs. Such substitution is price-induced, with the elasticity of substitution between the technologies typically set at around 5.

For other energy-intensive commodities used by industries, MMRF allows for a weak form of input substitution. If the price of cement (say) rises by 10 per cent relative to the average price of other inputs to construction, the construction industry will use 1 per cent less cement and a little more labor, capital and other materials. In most cases, as in the cement example, a substitution elasticity of 0.1 is imposed. For important energy goods (petroleum products, electricity supply, and gas) the substitution elasticity in industrial use is 0.25. Being driven by price changes, this input substitution is especially important in an ETS scenario, where outputs of emitting industries are made more expensive.

The National Electricity Market

The NEM is a wholesale market covering nearly all of the supply of electricity to retailers and large end-users in NEM regions. MMRF's represents the NEM as follows.

Final demand for electricity in each NEM region is determined within the CGE-core of the model in the same manner as demand for all other goods and services. All end users of electricity in NEM regions purchase their supplies from their own-state *Electricity supply* industry. Each of the *Electricity supply* industries in the NEM regions sources its electricity from a dummy industry called *NEM*, which does not have a regional dimension; in effect *NEM* is a single industry that sells a single product (electricity) to the *Electricity supply* industry in each NEM region. *NEM* sources its electricity from generation industries in each NEM region. Its demand for electricity is price-sensitive. For example, if the price of hydro generation from Tasmania rises relative to the price of gas generation from NSW, then *NEM* demand will shift towards NSW gas generation and away from TAS hydro generation.

The explicit modeling of the NEM enables substitution between generation types in different NEM regions. It also allows for inter-state trade in electricity, without having to trace

explicitly the bilateral flows. Note that WA and NT are not part of the NEM and electricity supply and generation in these regions is determined on a state-of-location basis.[15]
This modeling of the NEM is adequate for many MMRF simulations but for the ETS simulations reported in this paper much of it was overwritten by results from Frontier's detailed bottom-up model of the electricity system. The MMRF electricity-system structure described above provides a suitable basis for interfacing MMRF with the bottom-up model.

Services of energy-using equipment in private household demand

The final three industries shown in Table 1 are dummy industries that provide services of energy-using equipment to private households. These dummy industries enable households to treat energy and energy-using equipment as complementary which is not possible in MMRF's standard budget-allocation specification based on the Linear Expenditure System (LES).

Industry 56 provides private transport services to the household sector, using inputs of capital (private motor vehicles), automotive fuel and other inputs required for the day-to-day servicing and running of vehicles. Industry 57 provides the services of electrical equipment (including air conditioners) to households, using inputs of capital (electrical equipment) and electricity. Industry 58 provides the services of appliances used for heating and cooking, using inputs of capital (heating and cooking appliances), gas and electricity. Energy used by these three dummy industries accounts for all of the energy consumption of the residential sector.

Including these dummy industries improves the model's treatment of price-induced energy substitution and its treatment of the relationship between energy and energy equipment in household demand. For example, in the LES-based specification of household demand, if the price of electricity fell relative to the price of other goods and services, electricity would be substituted for other commodities, including electrical and heating appliances. But under the dummy-industry specification, a change in the price of electricity induces substitution only through its effect on the prices of electrical equipment services and private heating services. If the change in the electricity price reduces the price of electrical equipment services relative to the price of other products, then electrical equipment services (including its inputs of appliances and energy) will be substituted for other items in the household budget.

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[15] Note that transmission costs are handled as margins associated with the delivery of electricity to *NEM* or to the *Electricity supply* industries of WA and the NT. Distribution costs in NEM-regions are handled as margins on the sale of electricity from *NEM* to the relevant *Electricity supply* industries.

Additional enhancement for ETS modeling

In this section, enhancements to our modeling that are necessary for simulating the effects of a real-world ETS are explained. This involves:

- linking MMRF to GTEM, to enhance MMRF's handling of global aspects of the ETS and of changes to Australia's trading conditions;
- linking MMRF to Frontier's *WHIRLYGIG* electricity model, to enhance MMRF's electricity-supply detail;
- modeling abatement of non-combustion emissions; and
- modeling carbon sequestration in forest industries.

Linking with GTEM

As discussed in the introduction, the simulations reported in this Paper relate to a global ETS, with a global cap, a global price and allocations of permits to participating countries. GTEM was used to model the global scheme. Projections were obtained from GTEM for the global permit price and the allocation of permits across regions for each global-emissions target. The projections for the global permit price and Australia's emissions allocation were fed directly into MMRF. In MMRF, the global permit price and Australia's emissions allocation are naturally exogenous variables. Hence, a simple one-way link from GTEM to MMRF is sufficient.

GTEM also simulates changes in world trading conditions faced by Australia, with and without the global ETS. These are as represented in MMRF as changes in the positions of foreign export-demand and import-supply schedules. In MMRF, import supply is assumed to be perfectly elastic and foreign-currency import prices are naturally exogenous, once again allowing for one-way transmission from GTEM to MMRF.

For exports, however, foreign demand schedules are assumed to be downward sloping. In this case, one-way transmission is problematic because export prices and quantities are endogenous in both models. Despite the potential for feedback, the linking between GTEM and MMRF for export variables was done *via* one-way transmission from GTEM to MMRF. The main challenge was to deduce the changes in position of export-demand schedules in MMRF implied by the projected changes in export volumes and prices in GTEM.

In the remainder of this sub-section we give a short overview of the GTEM model, and then explain how changes in export demand schedules were transmitted to MMRF.

GTEM Overview

GTEM (Pant, 2007) and MMRF are based on a common theoretical framework – the ORANI model[16]. GTEM can be likened to a series of ORANI models, one for each national region, linked by a matrix of bilateral international trade flows. Similarly, MMRF can be likened to a series of ORANI models, one for each State and Territory, linked by a matrix of inter-state trade flows. But unlike the static ORANI model, MMRF and GTEM are recursively dynamic models, developed to address long-term global policy issues, such as climate-change mitigation costs.

Linking export variables

As outlined earlier, GTEM projections for the international permit price, Australia's emissions' allocation and foreign-currency import prices can easily be taken in to MMRF *via* a simple one-way link.[17]. But for exports, GTEM must provide MMRF with changes in the positions of the individual (downward-sloping) export-demand schedules, not changes in quantities or foreign-currency prices.

Figure 1 shows the method by which changes in export prices and quantities projected in GTEM (Figure 1a) are translated into movements in export-demand schedules in MMRF (Figure 1b). In Figure 1a, the initial export price-quantity point is A – at the intersection of the initial demand and supply schedules. In modeling the effects of a global ETS, demand moves from D to D' and supply from S to S', with the price-quantity point changing from A to B. The quantity exported changes by q, and export price by p. Note that the changes in demand and supply schedules are not directly observed – only the changes p and q.

Figure 1b shows how the information from GTEM (Figure 1a) is used to deduce the shift in the export-demand schedule required for the MMRF simulation.

First note that the elasticity of the demand curve in MMRF is shown as being the same as in GTEM. This is not necessary for the top-down procedure to work, but it does help avoid unduly large differences in *ex post* outcomes for export quantities and prices. GTEM's import substitution elasticities were adjusted to ensure consistency between its implied export-demand elasticities and the explicit elasticities in MMRF.

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[16]GTEM was derived from MEGABARE and the static GTAP model (Hertel, 1997). Aspects of MEGABARE are described in Hinchy and Hanslow (1996), Kennedy *et al.* (1998) and Tulpule *et al.* (1999).

[17] The only complication is that GTEM has a more aggregated commodity classification than does MMRF, so the GTEM information must first be mapped to MMRF commodities.

The values for p and q from the GTEM simulation are used to shift the export-demand schedule in MMRF in two directions. The schedule shifts horizontally by q and vertically by p. If in MMRF the supply schedule had the same shape as in GTEM, and if it were to shift in the same way, then in MMRF the *ex post* outcomes for export price and volume would be the same as in GTEM. Typically though, this was not the case: for several commodities MMRF's supply response was quite different from the supply response in GTEM. Thus, even though the shifts in export demand were the same, the observed changes in export price and quantity were quite different.

Linking with *WHIRLYGIG*

The idea that environmental issues could be tackled effectively by linking a CGE model with a detailed bottom-up energy model has a long history with Australian modelers. The first attempts were in a joint CoPS/ABARES project using ORANI and MENSA, which is an Australian version of the IEA's generic MARKAL framework.

MENSA/MARKAL is an optimization model of the Australian energy system. Adams, Dixon and Jones (1992) provide an exposition in a form that makes it accessible to CGE modelers. Powell (1993) discusses methodological issues arising in attempts to link such a model with a CGE model and presents an ambitious agenda for complete two-way integration: an agenda which is still not met in current practice.

Frontier's *WHIRLYGIG* model simulates the least-cost expansion and operation of generation and transmission capacity in the Australian electricity system. In linking MMRF to *WHIRLYGIG*, the electricity sector in MMRF is effectively replaced with *WHIRLYGIG*'s specification. MMRF provides information on fuel prices and other electricity-sector costs and on electricity demand from industrial, commercial and residential users. This is fed into *WHIRLYGIG*, which generates a detailed description of supply, covering generation by generation type, capacity by generation type, fuel use, emissions, and wholesale and retail electricity prices. Retail electricity prices are a key endogenous variable in both systems. Information is passed back and forth between the two models in a series of iterations that stop when the average retail price in the electricity model has stabilized. Experience suggests that up to three iterations for each year are necessary to achieve convergence.

There are a number of reasons to prefer linking to a detailed electricity model over the use of MMRF's standard treatment of electricity.

- *Technological detail*. MMRF recognizes six generation technologies (Table 1). *WHIRLYGIG* recognizes many hundreds, some of which are not fully proved and/or are not in operation.

For example, MMRF recognizes one form of coal generation. *WHIRLYGIG* recognizes many forms, including cleaner gasification technologies and generation in combination with carbon capture and storage (CCS). Having all known technologies available for production now or in the future allows for greater realism in simulating the technological changes available in electricity generation in response to a price on emissions. *WHIRLYGIG* also captures details of the interrelationships between generation types. A good example is the reliance by hydro generation on base-load power in off-peak periods to pump water utilized during peak periods back to the reservoir.

- *Changes in capacity*. MMRF treats investment in generation like all other forms of investment. Capital supply is assumed to be a smooth increasing function of expected rates of return which are set equal to current rates of return. Changes in generation capacity, however, are generally lumpy, not smooth, and investment decisions are forward looking, given long asset lives. *WHIRLYGIG* allows for lumpy investments and for realistic lead times between investment and capacity change. It also allows for forward looking expectations, which aligns more with real-world experience than does MMRF's standard static assumption. The demand for electricity is exogenous in *WHIRLYGIG* but when demand is endogenised by running *WHIRLYGIG* linked to MMRF, investment in the electricity sector is essentially driven by model-consistent expectations.
- *Policy detail*. Currently, in Australia there are around 100 policies at the state, territory and commonwealth levels affecting electricity generation and supply. These include: market-based instruments to encourage increased use of renewable generation; regulations affecting the prices paid by final residential customers; and regional policies that offer subsidies to attract certain generator types. Some of these policies interact with an ETS. For example, the market-based Renewable Energy Target (RET), which is designed to ensure that 20 per cent of Australia's electricity supply will come from renewable sources by 2020, operates by requiring electricity retailers to acquire and surrender Renewable Energy Certificates (RECs). These RECs have a market price which will be sensitive to an ETS. Associated interactions and policy details are handled well in *WHIRLYGIG*, but are generally outside the scope of stand-alone modeling in MMRF.
- *Sector detail*. In MMRF, electricity production is undertaken by symbolic industries – *Electricity-coal Victoria*, *Electricity-gas NSW* etc. In *WHIRLYGIG*, actual generation units are recognized – unit x in power station y located in region z. Thus results from the detailed electricity model can be reported at a much finer level and in a way which industry experts fully understand. This adds to credibility in result reporting.

Linking

The linking of *WHIRLYGIG* to MMRF proceeds as follows. For either a base-case or a policy simulation, an initial MMRF simulation is conducted, with the electricity system unconstrained.

From this simulation come annual projections for:

1. electricity demand by industry and region in petajoules (Pj); and
2. prices for labor, energy carriers such as coal, and other relevant material inputs.

These projections are supplied to *WHIRLYGIG.* The Frontier modelers take the annual demand projections, generate within-year load profiles, and update their estimates for the variable costs of generation for each option. The electricity model is then run (with appropriate constraints relating to $C0_2$–e emissions if necessary) to provide annual projections by region for:

3. sent-out generation (GWh) by type, aggregated to MMRF's level of detail[18];
4. fuel usage by generation type (Pj), aggregated appropriately;
5. emissions by generation type (tonnes of CO_2-e), aggregated appropriately;
6. capacity by generation type (GW), aggregated appropriately;
7. wholesale electricity prices ($ per GWh); and
8. retail electricity prices ($ per GWh).

Items 3-8 are then input to MMRF, enabled by closure changes that in effect turn off MMRF's treatment of electricity supply and investment. Details of the closure changes are given in Table 3. The first column shows the *WHIRLYGIG* variable being transferred. The second column shows the MMRF variable targeted. Most of these variables are naturally endogenous but must be made exogenous. The final column gives the MMRF variable – typically a naturally exogenous variable – that is endogenized to allow the targeted variable to be exogenized.

The changes in generation mix imposed on MMRF are initially cost-neutral and so have no effect on the average price of the *Electricity supply* industry. *WHIRLYGIG* estimates of changes in average wholesale and prices of electricity in each region are introduced into MMRF *via* changes in *Other costs* in MMRF's generation and electricity supply industries.

Imposing these *WHIRLYGIG* values in MMRF and re-running completes the first iteration. Revised values for items 1 and 2 are passed to *WHIRLYGIG* which then re-calculates values for variables 3 to 8. Iterations continue until between successive iterations the retail prices of electricity in each region stabilize.

Abatement of non-combustion emissions

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[18]Three stages of electricity production are identified in *WHIRLYGIG* and MMRF. Generation sent out is raw generation net of electricity used in the generation process. Final-use electricity is electricity sent out less transmission and distribution losses. Any generation option in the detailed electricity model associated with the use of coal is aggregated into a single number for the MMRF industry *Electricity – coal*, etc.

In the ETS modeling reported in this paper, shielding is implemented as a general production subsidy to offset the combined direct and indirect effects of the emissions price on an industry's average cost. The direct effects arise from the imposition of the emission price on the industry's combustion emissions or on the emissions directly associated with its activity (e.g., industrial and fugitive emissions); the indirect effects arise from the increased cost of electricity. To offset the direct impacts of a carbon price, the proposed ETS specified shielding proportional to the emission price and the shielded industry's output level. Abatement of non-combustion emissions

Non-combustion (or *Activity*) emissions include: agricultural emissions (largely from animals); emissions from land-clearing or forestry; fugitive emissions (e.g., gas flaring); emissions from industrial processes (e.g., cement manufacture); and emissions from land-fill rubbish dumps. In modeling with MMRF, it is assumed that in the absence of an emissions price, non-combustion emissions move with industry output, so that non-combustion emissions intensity (emissions per unit of output) is fixed.

MMRF's theory of abatement of non-combustion emissions in the presence of an emissions price is similar to that developed for GTEM. It assumes that as the price of CO_2-e rises, *targeted* non-combustion emissions intensity (emissions per unit of output) falls (abatement per unit increases) through the planned introduction of less emission-intensive technologies. More specifically, for *Activity* emitter i in region q it is assumed that abatement per unit of output can be achieved at an increasing marginal cost according to a curve such as that shown in Figure 2a. In this figure, units are chosen so that complete elimination of non-combustion emissions corresponds to an abatement level of 1. However, complete elimination is not possible. So as shown in the figure, the marginal cost of abatement goes to infinity as the abatement level per unit of output reaches a maximum level, 1-MIN, where MIN is the proportion of non-combustion emissions that cannot be removed. From Figure 2a, an intensity function for emissions can be derived of the form:

$$Intensity_{i,q} = MAX_{i,q}\left\{MIN_{i,q},\ F_{i,q}(T)\right\} \quad (9),$$

where:

$Intensity_{i,q}$ is the target level of non-combustion emissions intensity;

$MIN_{i,q}$ is the minimum possible level of emissions intensity; and

$F_{i,q}$ is a non-linear monotonic decreasing function of the real level of the emissions price, T (\$ per tonne of CO_2-e in constant 2010 prices).

This is illustrated in Figure 2b which shows for a typical *Activity* abater the relationship between targeted emissions intensity and emissions price, with intensity indexed to 1 for T = 0.

To ensure that emissions intensities do not respond too vigorously to changes in the emissions price, especially at the start of a simulation in which the price of CO_2-e rises immediately from zero, a lagged adjustment mechanism is also put in place, allowing actual emissions intensity to adjust slowly towards targeted emissions intensity specified by (9).

In MMRF the abatement cost per unit of output (the shaded area in Figure 2a) is imposed as an all-input using technological deterioration in the production function of the abating industry.[19]

Land use in forestry

In MMRF, land is an input to production for the agricultural industries and forestry. Prior to the ETS project, the standard treatment was to treat land as industry specific and in fixed supply. Hence when a land-using industry expanded, the scarcity value of its land increased, leading to an increase in its rental price.

For the ETS simulations, land is considered region-specific but not industry-specific and there are regional supply constraints. This means that within a region, an industry can increase its land usage but that increase has to be met by reduced usage by other industries within the region. Land is assumed to be allocated between users to maximize the total return to land subject to a Constant Elasticity of Transformation (CET) constraint defining production possibilities across the various land-using sectors. This is the same treatment as adopted in GTAP and GTEM. With this mechanism in place, if demand for bio-sequestration offsets pushes up demand for land in the forestry sector, then forestry's use of land will increase, increasing the region-wide price of land and causing non-forestry industries to reduce their land usage and overall production.

[19] Here, the MMRF treatment differs from the treatment in GTEM where it is assumed that the change in technology necessary to achieve the reduction in emission intensity is costless.

Base case

The base case is the control projection against which the policy scenario (with an ETS in place) is compared. For the ETS work, much importance was placed on establishing a detailed base case with a credible projection for emissions across regions and sectors. There were two reasons for this. The first is that the cost of implementing the ETS in each year depends critically on the underlying level of base-case emissions (Weyant and Hill, 1999). The second is that acceptance of the modeling outcomes, including the level of shielding necessary for emission-intensive industries, is reliant on the credibility of the base case.

In subsection 4.1 we describe the key assumptions underlying the base case. Subsections 4.2 to 4.5 contain base case projections for macroeconomic variables, industry outputs, greenhouse gas emissions and electricity generation.

Key assumptions

The base case for the ETS simulation reported in this Paper incorporates a large amount of information from specialist forecasting agencies. MMRF traces out the implications of the specialists' forecasts at a fine level of industrial and regional detail. Information imposed on the model included:

- state/territory macroeconomic forecasts to 2014 based on information provided by Frontier Economics;
- national-level assumptions for changes in industry production technologies and in household preferences developed from MONASH and MMRF historical-decomposition modeling[20];
- forecasts through to 2014 for the quantities of agricultural and mineral exports from a range of industry sources;
- estimates of changes in generation mix, generation capacity, fuel use, emissions and wholesale prices from Frontier Economics' electricity modeling;
- forecasts for state/territory populations and participation rates drawing, in part, on projections in the Treasury's Intergeneration Report (IGR, Department of Treasury, 2007);
- forecasts for land-use change and for forestry sequestration from experts at ABARES; and
- forecasts for changes in Australia's aggregate terms of trade and for the foreign export and import prices for Australia's key traded goods in agriculture, mining and manufacturing drawn from simulations of GTEM undertaken for the Treasury.

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20 Historical decomposition modeling is discussed in Dixon and Rimmer (2002, Paper 5) and in Dixon, Koopman and Rimmer (2012).

To accommodate this information in MMRF, numerous naturally endogenous variables are made exogenous. To allow the naturally endogenous variables to be exogenous, an equal number of naturally exogenous variables are made endogenous. For example, to accommodate the exogenous setting of the aggregate terms of trade, an all-commodity and all-region shift variable, naturally exogenous in MMRF but endogenous in the base-case simulation, imparts an equi-proportionate change in the positions of foreign demand curves. Another example relates to private consumption. In the base case, real private consumption by state (a naturally endogenous variable) is set exogenously by allowing the average propensity to consume in each state to adjust endogenously.

Base-case projections for selected macroeconomic variables

Figures 3a to 3c (not presented, but available on request) show base-case projections for selected national macroeconomic variables. The following are some key features.

- Real GDP grows at an average annual rate of 3.1 per cent between 2010 and 2020, slowing to an average rate of 2.6 per cent between 2020 and 2030. Average annual growth over the full projection period (2.9 per cent) is consistent with the historical norm for Australia. Note that in the first four years after 2010, growth exceeds three per cent, supported by strong growth in exports as the world recovers from the global financial crisis. Thereafter, GDP growth is projected to stabilize, eventually declining slowly in line with demographic projections from the IGR.
- In line with recent history, the export-oriented states – QLD and WA states – are projected to be the fastest growing state economies, followed by NSW and VIC. SA and TAS are the slowest growing, though the gap between the slowest and fastest growing states and territories is a little less than in recent times.
- Real national private consumption grows at an average annual rate of 3.0 per cent in the first half of the period and 2.9 per cent in the second half. This time profile is similar to that for real GDP: initially strong, then stabilizing and eventually declining slowly.
- Over the fifteen years leading up to 2010, the volumes of international exports and imports grew rapidly relative to real GDP. This reflects several factors states – declining transport costs, improvements in communications, reductions in protection in Australia and overseas and technological changes favoring the use of import-intensive goods such as computers and communication equipment.[21] All these factors are extrapolated into the early years of the base case, but their influence is assumed to weaken over time. On average, trade volumes grow relative to GDP by about 1.5 per cent per year. Unlike in recent history, import growth is projected to be in line with export growth, implying little improvement in the current imbalance between export and import volumes.

[21] The effects of changes in technology and preferences in explaining the rapid growth in trade are discussed in: Dixon, Menon and Rimmer (2000).

- Australia's terms of trade are assumed to decline sharply in the first few years of the base case, returning to a historically normal level by 2020 from their initial 50-year high.

Base case projections for national industry production

Table 4 and Figures 4a to 4i (not presented, but available on request) show base-case projections for industry output at the national level.

- *Electricity generation – other renewable* (industry 37) has the strongest growth prospects, with average annual growth of 7.3 per cent, of which most occurs in the first half of the period. This industry generates electricity from renewable sources other than hydro. Its prospects are greatly enhanced by the Australian government's mandated target for the share of renewable energy in total electricity generation which is integrated into the modeling. Other forms of electricity generation have mixed prospects. Generation from gas (industry 33, rank 8) is projected to grow at a relatively strong average annual rate of 4.0 per cent, supported by environmental policies at both the federal and state level. The same policies restrict the average annual growth rate of emission-intensive coal generation (industry 32, rank 52) to 0.4 per cent. It is assumed that generation from oil products (industry 34, rank 55) and hydro (industry 36, rank 54) will not change over the projection period. Production of hydro-electricity is constrained by environmental factors, while the detailed electricity-sector modeling indicates little scope for oil-based generation to change.
- In the projections, the production of the key electricity generation sectors does not evolve smoothly over time. For example, annual growth for other renewable generation in the four years 2014 to 2017 is 16.5 per cent, 31.0 per cent 19.8 per cent and 7.1 per cent. These numbers come directly from the detailed electricity modeling which allows for large and discrete increases in renewal generation capacity. Similarly, there can be discrete changes in utilization of existing capacity.
- Projected growth in overall *Electricity supply* (industry 38, rank 37) is relatively slow at 1.7 per cent per annum. In line with recent history, the base case includes an autonomous annual 0.5 per cent rate of electricity-saving technological change in all forms of end-use demand. This, coupled with relatively slow average annual growth in two of the main electricity-using industries – *Aluminum* (1.8 per cent) and *Private heating services* (1.7 per cent) – explains the relatively slow growth projected for *Electricity supply*.
- Projections of strong growth of softwood plantations on land previously used in marginal broad-acre agriculture The ABARES GTEM model projects significant growth in world demand for *Forestry* which absorbs much of the additional forestry supply with relatively little change in basic price. The expansion in exports explains how *Forestry* can expand strongly while its main domestic customer, *Wood products* (industry 17, rank 43), has a relatively low growth ranking.

- *Air transport* is the third ranked industry, with a projected average annual growth rate of 5.2 per cent. Prospects for this industry are good because of expected strong growth in inbound tourism, and the assumed continuation of a taste shift in household spending towards air and away from road as the preferred mode for long-distance travel.
- *Rail freight transport* (industry 47, rank 9) and *Rail passenger transport* (industry 46, rank 11) are each ranked in the top 15 industries by growth prospect. *Rail freight* is used mainly to transport bulk commodities (coal, iron ore and grains) to port for export. It grows strongly in the base case because of strong growth in coal exports. *Rail passenger transport* is dominated by urban rail services. It is assumed that road congestion in urban areas will intensify through the projection period, inducing commuters to substitute rail for road travel.
- Rapid growth in *Communication services*, *Business services* and *Financial services* (industries 50, 52 and 51, ranks 4, 5 and 10) reflects the assumption that changes in technology through the projection period will favor intermediate usage of these services strongly and that comparatively rapid productivity growth will reduce their prices relative to consumer prices in general.
- *Gas mining* and *Coal mining* (industries 10 and 8, ranks 6 and 7) have good growth prospects, reflecting an assumption of very strong growth in exports of Liquefied Natural Gas (LNG) and coal. Note that the main domestic users of gas and coal – *Gas supply* (industry 39, rank 25) and coal-fired electricity generation – have relatively low growth prospects. The former supplies town gas in the Eastern states, and is closely connected to *Private heating services*, which has projected average annual growth of just 1.7 per cent. As noted above, base-case growth in coal-fired electricity generation is very weak.
- Prospects for the non-energy mining industries are governed by projections for world demand taken from GTEM. Production of *Oil* is expected to increase at an average annual rate of just 0.6 per cent, reflecting estimates of supply availability from current reserves.
- Forecasts for the agricultural sector are, in the main, determined by the prospects of downstream food and beverage industries. These have below-average growth prospects, reflecting fairly weak growth in exports and expected increases in import penetration on local markets. *Grains* (industry 4, rank 24) has the best growth prospects of the agricultural industries, due mainly to relatively strong export-demand growth forecast by GTEM. *Agricultural services, fishing and hunting* (industry 6, rank 35) is projected to grow relatively slowly due to resource constraints on fishing stocks.
- Most manufacturing industries have weak growth prospects, due mainly to increases in import competition and weak growth in exports. The effects of increasing import competition are seen most clearly in the prospects for *Other manufacturing* (industry 31, rank 57) and *Textiles, clothing and footwear* (industry 16, rank 58), which are the only industries expected to contract over the projection period. Despite projected strong

growth in exports, growth in output for the *Iron and steel* industry (25, rank 47) is projected to be weak due to slow growth in domestic demand. *Alumina* and *Aluminum* (26 and 27, ranks 26 and 33) have better growth prospects than *Iron and steel* because they have much larger export propensities and world demand for these products is expected to be stronger.

- Nearly all of the remaining industries have close to average growth prospects. The prospects for *Construction services* (industry 41, rank 18) reflect the model's projection for growth in real national investment. *Trade services* (industry 42, rank 27) sells widely throughout the economy. Its growth rate, though, is below that of real GDP because of adverse taste and technology shifts.

Base case projections: emissions by source

Figure 5 gives a year-to-year picture of the level of emissions at the national level. It covers all emissions except for emissions from land clearing in line with Kyoto accounting principles. Table 5 gives region-specific details on the sources of emissions in the base case.

- In aggregate, emissions are projected to grow at an average annual rate of 1.8 per cent between 2010 and 2020, 1.2 per cent between 2020 and 2030, and 1.5 per cent across the full projection period. By 2020, emissions are projected to be 19.6 per cent higher than in 2010. Emission levels at 2030 are projected to be 34.5 per cent above 2010 levels.
- The largest source of emissions is electricity generation, especially generation from coal combustion. In 2010, electricity contributed almost 36 per cent to total emissions. But the detailed electricity modeling indicates that average annual growth in emissions from electricity will be only 0.2 per cent through the projection period. This is a little below the assumed growth rate in output (generation) of 0.4 per cent, reflecting improved fuel efficiency.
- The second largest source of emissions is agriculture, with a 2010-share of 17.7 per cent. In the Kyoto-accounting framework, most of Australia's agricultural emissions come from methane emitted by cattle and sheep. Base-case growth prospects for these livestock industries are well below GDP growth: *Sheep and beef cattle* (1.6 per cent per annum); *Dairy cattle* (0.9 per cent) and *Other livestock* (1.3 per cent). Average annual growth in emissions from agriculture is 1.3 per cent.
- Other stationary-energy sources contribute 17.0 per cent to total emissions in 2010. These include residential, industrial and commercial space heating. Emissions from other stationary sources are projected to grow at an average annual rate of 2.2 per cent. This is below the growth rate of real GDP, reflecting the relatively slow growth of *Private heating services* (1.7 per cent per annum) and *Other manufacturing* (-0.1 per cent).

- Transport contributes 16.0 per cent to total emissions in 2010, and has projected emissions growth of 1.6 per cent per annum. Around 60 per cent of transport emissions are due to *Private transport services*, which is projected to grow at an average annual rate of 1.7 per cent. Much of the remaining transport emissions come from *Road freight transport*, which grows at an average annual rate of 3.0 per cent. Emissions grow by less than output in these two key industries because it is assumed that use of bio-products will increase.
- Of the remaining sources, growth in fugitive emissions is highest, reflecting rapid growth in the mining of gas and coal. Industrial-process emissions are projected to grow at an average annual rate of 1.4 per cent, reflecting growth in output from *Cement* and the metals-manufacturing industries. Emissions of methane from landfill waste dumps are assumed to grow in line with recent history.
- The final category is Forestry. The modeling ignores all emissions from land-use change except for sequestration from forestation and reforestation in areas where the preceding vegetation or land use was not forest. For the base case, data on forestry sequestration were supplied by ABARES. The ABARES projections take account of the life cycle of individual forests established since 1990, accounting for carbon sequestered when the forest is planted and growing, and for carbon released when the forest is harvested. Note that this makes a negative contribution to emissions in 2010 but positive contributions in 2020 and 2030.

Aggregate emissions per $ of real GDP (national emissions intensity) is projected to fall, on average, by 1.4 per cent per year. Much of this has been explained in our discussion of growth rates in emissions by source. In addition, there is a structural effect. The service industries, *Communication services*, *Financial and business services*, *Dwelling ownership*, *Public services* and *Other services*, together contribute around 40 per cent of GDP but emit relatively little (directly and indirectly *via* their use of electricity) per unit of real value added. In the base case, they contribute significantly to growth in real GDP, but have little impact on growth in emissions, generating a fall in emissions per unit of GDP.ETS Simulation design

Introduction

In Section 6 we report MMRF simulations of a global ETS with a global allocation of permits sufficient to reduce global emissions in 2050 to 5 per cent below their level in the year 2000.[22] The simulations examine the effects of this scheme out to 2030. The effects are reported as deviations from the values of variables in the base-case projection described in Section 4.

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[22] This is the scheme identified by the Australian Treasury as the CPRS-5; CPRS stands for Carbon Pollution Reduction Scheme.

The main inputs to the MMRF policy simulation are projected effects of the scheme on:

- various aspects of electricity supply, as modeled by Frontier Economics;
- vehicle use by vehicle type, as modeled by the Australian Bureau of Infrastructure, Transport and Regional Economics (BITRE) and by the Commonwealth Scientific and Industrial Research Organization (CSIRO);
- forestry sequestration and plantation use of land from land-use experts at ABARES;
- foreign-currency import prices and the positions of foreign export-demand schedules from the GTEM model; and
- the global emissions price and Australia's allocation of global permits as specified by the Australian Treasury.

In the remainder of this section, we first outline the key features of the scheme (subsection 5.2), including the permit price and Australia's allocation of emission permits. In subsection 5.3 we discuss the other key inputs listed above. Key assumptions regarding the behavior of the macro-economy in the MMRF simulations are discussed in subsection 5.4.

Scheme design

Table 6 summaries design features of the modeled ETS scheme.

Permit price

The GTEM projection of the international permit price, converted to real Australian dollars in MMRF, is given in Figure 6. The starting price is $24.3 per tonne by the year 2012. Thereafter it increases at an annual rate of around 4 per cent, reaching $33.3 per tonne in 2020 and $49.3 per tonne in 2030.

In MMRF, the permit price is modeled as a tax imposed per unit of CO_2-e. In keeping with the design of the scheme, initially the tax is imposed on all sources of emissions other than agriculture and transport. From 2012 onwards it is extended to transport, and from 2015 to agriculture. Thus all emissions are priced at the same rate after 2015.

Australia's allocation of permits

Figure 7 shows Australia's allocation of permits under the global ETS. It also shows Australia's projected path for emissions in the base case where no ETS is in place. In the base case, emissions rise from 528 Mt of CO_2-e in 2010 to 710 Mt in 2030. Australia's permit allocation in 2030 is for emissions of 365 Mt of CO_2-e.

The gap between base-case emissions and permit allocation represents the international abatement obligation faced by Australia under the global ETS. As shown in Figure 7 the gap steadily widens over time, so that by 2030 the abatement obligation is 345 (= 710 -365) Mt of CO_2-e. Australia can meet this in two ways: by domestic abatement in response to the emission price; and by purchasing permits from overseas. As will be seen, based on the price profile in Figure 6, Australia ends up importing a large number of permits.

Electricity inputs from Frontier *WHIRLYGIG*

The Frontier electricity model provides projections (deviations from base-case values) for electricity generation, energy use, generation capacity, emissions and electricity prices. These projections are accommodated in the MMRF modeling *via* the closure changes given in Table 3.

Road transport inputs from the BITRE and CSIRO

The BITRE and CSIRO provide data for changes away from base-case values in fuel use and emissions for private transport by region. The assumptions suggest that to 2030 the emissions price will have little impact on fuel choice and emissions in private transport.[23]

Projections for the use of gasoline, diesel and LPG in road transport are accommodated in MMRF by endogenous shifts in fuel-usage coefficients in industries' production functions. The BITRE/CSIRO emissions projections are accommodated by endogenous shifts in emissions per unit of fuel used.

Forestry land and bio-sequestration inputs from ABARES

According to the ABARES inputs, the global ETS would have a significant impact on forestry production and forest bio-sequestration, as shown in Figure 8. By 2030, forestry production has risen 80 per cent above its base-case level and sequestration has risen by 30 Mt.

Corresponding changes in land under forestry are also imposed. With total land availability by region is fixed, land available for agriculture falls.

The ABARES estimates of the response of forestry sequestration to the emissions price is accommodated in MMRF by endogenous shifts in emissions per unit of forestry output.

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[23] Note that the post-2030 ETS modeling reported by the Treasury has electric-powered cars taking significant market share away from vehicles relying on internal combustion technologies.

Trade variables based on information from GTEM

Projections of changes in foreign-currency import prices and in the positions of foreign export-demand schedules for Australia in response to a global emissions price are sourced from GTEM modeling.[24] The GTEM projections are summarized by changes in the aggregate terms of trade shown in Figure 9.

The long-term effect of the ETS on Australia's terms of trade is negative. This is driven mainly by a reduction in the world price of coal as users switch to less emission-intensive fuels. However, when China joins the international coalition in 2015[25] there is a temporary jump in global coal prices as Chinese demand is diverted from local to foreign supplied product. This effect dissipates in 2020 when India and the rest of the world join the scheme and world coal demand falls.

Assumptions about gas reserves and gas prices from various industry sources

In the base-case and policy simulations, gas reserves in the eastern Australia gradually close down and are replaced by supplies from WA and the NT. WA and NT gas is produced for export as well as for local use and its price is set by the global gas price. Gas from eastern sources is produced for local demand and its price is determined, in the main, by domestic factors. As eastern fields are replaced by WA and NT gas, so the prices paid by customers in the eastern states move to international parity. In the base-case and policy simulations, it is assumed that eastern gas prices rise gradually to reach full international parity by 2030.

Assumptions for the macroeconomy in the policy scenarios

The following assumptions are made for key aspects of the macro economy in the policy (with-ETS) simulation.

Labor markets

At the national level, lagged adjustment of the real-wage rate to changes in employment is assumed. Adoption of the ETS can cause employment to deviate from its base-case value initially, but thereafter, real wage adjustment steadily eliminates the short-run employment consequences of the emissions price. In the long run, the costs of emissions pricing are realized almost entirely as a fall in the national real wage rate, rather than as a fall in national

[24] The methodology used to introduce the GTEM results into MMRF is described in subsection 3.1.

[25] The Treasury's CPRS assumed a multi-stage approach to international emissions trading. Developed countries act first, then developing countries join over time.

employment. This labor-market assumption reflects the idea that in the long run national employment is determined by demographic factors, which are unaffected by the adoption of an emissions price.

At the regional level, labor is assumed to be mobile between state. Labor is assumed to move between regions so as to maintain inter-state unemployment-rate differentials at their base-case levels. Accordingly, regions that are relatively favorably affected by emissions pricing will experience increases in their labor forces as well as in employment, at the expense of regions that are relatively less favorably affected.

Private consumption and investment

Private consumption expenditure is determined *via* a Keynesian consumption function that links nominal consumption to household disposable income (HDI). HDI includes the lump-sum return of permit income which is part of the ETS design. In the ETS simulations, the average propensity to consume (APC) is an endogenous variable that moves to ensure that the balance on current account in the balance of payments remains at its base-case level. Thus any change in aggregate investment brought about by the ETS is accommodated by a change in domestic saving, leaving Australia's call on foreign savings unchanged.

Investment in all but a few industries is allowed to deviate from its base-case value in line with deviations in expected rates of return on the industries' capital stocks. In the policy scenarios, MMRF allows for short-run divergences in rates of return from their base-case levels. These cause divergences in investment and hence capital stocks that gradually erode the initial divergences in rates of return. Provided there are no further shocks, rates of return revert to their base-case levels in the long run. An exception to this rule is the electricity generating industries, for which changes in capacity are taken from the detailed electricity model. The changes are accommodated by allowing the required rates of return on investment to shift endogenously.

Government consumption and fiscal balances

MMRF contains no theory to explain changes in real public consumption. In these simulations, public consumption is simply indexed to nominal GDP. The fiscal balances of each jurisdiction (federal, state and territory) as a share of nominal GDP are fixed at their values in the base case. Budget-balance constraints are accommodated by endogenous movements in lump-sum payments to households.

Production technologies and household tastes

MMRF contains many variables to allow for shifts in technology and household preferences. In the policy scenarios, most of these variables are exogenous and have the same values as in the base-case projection. The exceptions are technology variables that are made endogenous to allow for:

- changes in the fuel intensity of electricity generation, based on data from the detailed electricity modeling;
- the new production technology required to achieve the reductions in emissions intensity implied by equation (9) (subsection 3.4); and
- the replacement of gasoline and diesel with cleaner (but more expensive) biofuels and electricity in the provision of private transport services. This is based on information from the detailed road-transport modeling.

Economic effects of the ETS

Introduction

Figure 10 illustrates the interpretation of MMRF results for the effects of an ETS on a particular variable, e.g., real GDP. MMRF generates a base case, which is a projection through time for the variable without an ETS (Section 4). The base case is depicted as the path between points A and B. The model is also used to produce an alternative projection in which endogenous variables shift away from base-case trends to accommodate the exogenous shocks associated with the ETS (Section 5). A typical alternative projection for the variable considered in Figure 10 is shown as the path between points A and C.

Figure 10 has been drawn with the base-case path and the ETS path both smooth and with the deviation of the ETS path from the base-case path also growing smoothly. In this case, it is apparent that there are a number of options for reporting the effects of the ETS, all of which will tell a similar story.

One option is to compare average annual growth in the base case with average annual growth in the ETS simulation. In terms of average annual rates between 2010 and 2030, we would be comparing:

$$100\times\left\{\left(\frac{B}{A}\right)^{1/20}-1\right\} \text{ with } 100\times\left\{\left(\frac{C}{A}\right)^{1/20}-1\right\} \qquad (10)$$

Note that in the smooth case shown in Figure 10, comparing average annual growth rates over shorter periods will not be seriously misleading relative to the whole-period comparison.

Alternatively, deviations can be reported by comparing the value of variables in a specific year in the ETS simulation with values in the base case. Deviations could be expressed as percentage changes from base-case values in the final year of the simulation period:

$$100\times\left\{\left(\frac{C}{B}\right)-1\right\} \tag{11}$$

or as absolute ($m or Mt, etc.) changes from base-case values:

$$(C-B) \tag{12}$$

Again, in the smooth case intermediate-year comparisons will not be seriously misleading relative to the final-period comparison.

Users of model-based projections of the effects the ETS policy have often been tempted to select their preferred reporting option according to how it is likely to be interpreted by non-specialists. Proponents of the ETS opt for measures that appear superficially to suggest that its cost will be small while opponents opt for measures that appear to suggest large costs.

To illustrate this, in Table 7 we report the effects of the ETS on Australian real GDP in 2020 and 2030 according to measures (10)-(12) and according to a fourth measure (13) that emphasizes that negative deviations from base-case values are compatible with continuing strong growth in an economy that would have been enjoying strong growth in the absence of the ETS. This fourth measure expresses the deviation as the number of months of base-case growth that are lost as a consequence of the ETS:

$$-12\times\frac{\left\{\left(\frac{C}{B}\right)-1\right\}}{\left\{\left(\frac{B}{A}\right)^{1/20}-1\right\}} \tag{13}$$

Unsurprisingly, proponents of the ETS usually opt for the first or fourth measure, while opponents tend to concentrate on the second or especially the third measure.

More fundamental than this cosmetic point, is the question of how to report results in cases in which, unlike Figure 10, the base-case path or the ETS path or the deviation between the paths does not develop smoothly. As shown in Figures 9a to 9c and 11, when we incorporate results from a bottom-up model of the electricity system like *WHIRLYGIG* or a world-trade model like GTEM, the paths and deviations for electricity variables and the terms of trade may not develop smoothly. One option is to report a time profile of the deviations of base-case values from ETS values. Another is to use an aggregate measure that includes all the year-specific deviations. The present value of the deviations is an obvious choice.

Results

The rest of this section contains a discussion of deviations from base case values in the ETS simulations. National impacts are dealt with first, followed by state and sub-state outcomes. Projected deviations for 2030 are given in Tables 11 (macro variables), 13 (national industry output) and 14 (emissions of CO_2-e). A series of charts provide time profiles of the deviations for key variables. In the discussion below, which focuses mainly on the final year (2030), italicized headings outline the main features of the results.

Our explanations of the national-level macroeconomic results are informed by a stylized back-of-the-envelope macro model that we constructed to demonstrate the macroeconomic mechanisms underlying the MMRF results. Details of the stylized model are in the Appendix.

National variables

In the short run, the ETS reduces employment relative to its base-case level. Over time, the employment deviation remains fairly constant as the national real wage rate adjusts downwards.

The explanation of macro effects begins with the impacts on the national labor market. Figure 11 shows percentage deviations in national employment, the national real wage rate and the national real cost of labor. The real wage is defined as the ratio of the nominal wage rate to the price of consumption. The real cost of labor is defined as the ratio of the nominal wage rate to the national price of output (measured by the factor-cost GDP deflator). Assuming competitive markets, the equilibrium nominal wage will be equal to the value of the marginal product of labor.

According to the labor-market specification in MMRF, the real wage rate is sticky in the short run (i.e., the nominal wage moves with the price of consumption) but adjusts with a lag downwards (upwards) in response to a fall (rise) in employment. When the ETS starts up, the emissions price increases the price of spending (e.g., household consumption) relative to the price of output, and hence moves the nominal wage above the value of the marginal product of labor in the short run. In Figure 11 this shows as an increase in the real cost of labor relative to its base-case value and a fall in employment relative to base case.

If there were no further shocks, over time the real wage rate would progressively fall relative to base case levels, reducing the real cost of labor and forcing employment back to its base-case level. In the ETS simulations, however, shocks continue with the permit price increasing under a progressively tighter regime of tradable permits. Hence as shown in Figure 11, the employment deviation is never fully eliminated and the real wage rate declines steadily relative to its base-case value. In 2030, the employment deviation is -0.2 per cent, while the real wage rate is down 2.6 per cent.

Note that the deviations in employment and the real wage rate are not smooth, especially in the early years, despite the smoothness of the permit-price trajectory (Figure 6). This reflects a number of factors:

- the changing coverage of the ETS scheme, with transport industries entering in 2012 and agricultural industries entering in 2015 (Table 6);
- large changes in electricity generation and capacity by technology type projected by the detailed electricity modeling (Figures 9a and 9b); and
- swings in the national terms of trade projected by GTEM (Figure 9).

The swings in the terms of trade have a significant impact on the labor market in the short run. An increase in the terms of trade causes the price of final domestic demand (which *includes* import prices but *excludes* export prices) to fall relative to the price of GDP (which *excludes* import prices but *includes* export prices), leading to downward pressure on the real cost of labor. Hence, relative to base, changes in the terms of trade contribute positively to employment in the first few years of the projection when the terms of trade rise.

A final point to note is that even though the fall in national employment is fairly small, this does not mean that employment at the individual industry or regional level remains close to base-case values. In most industries and regions, there are significant permanent employment responses to the ETS, compounding or defusing existing (base-case) pressures for structural change.

The ETS depresses the economy-wide labor/capital ratio.

Figure 12 shows percentage deviations from base-case values for the national capital stock and the real cost of capital. The latter is defined as the ratio of the nominal rental cost of capital relative to the national price of output (measured by the factor-cost GDP deflator). In 2030, the capital-stock deviation is -1.7 per cent, implying an increase in the ratio of labor to capital of around 1.6 per cent. In the same year, the real cost of capital is up 0.6 per cent relative to its base case level.[26]

The reduction in capital is due, in part, to changes in relative factor prices. As the real cost of labor falls relative to the real cost of capital (compare Figure 11 with Figure 12), producers substitute labor for capital across the economy. In 2030, with the real cost of capital relative to the real cost of labor rising by around 1.1 per cent, the shift in relative factor prices could

[26] In general terms, as the real cost of labor falls, so the real cost of the other key factor of production (capital) will rise.

be expected to contribute about 0.5 × 3.0 = 1.5 percentage points to the eventual 1.6 per cent increase in the labor/capital ratio.[27] In addition, there is a compositional effect due to the fact that the energy-related mining and coal-fired electricity sectors that are suppressed by the ETS are capital-intensive.

With little change in employment and technology, the reduction in capital leads to a fall in real GDP at factor cost.

The percentage change in real GDP at factor cost is a share-weighted average of the percentage changes in quantities of factor inputs (labor, capital and agricultural land), with allowance for technological change. Figure 13a shows, in stacked annual columns, the contribution of each component other than land to the overall percentage deviation in real factor-cost GDP. Although land can be re-allocated between uses, its availability overall is fixed.

Real GDP at factor cost falls relative to its base-case level in all years of the simulation. In the final year it is down 0.9 per cent. The possibility of achieving large cuts in emissions at a relatively mild macro-cost is a common theme in all of the analyses of carbon taxes and emission trading schemes undertaken at CoPS.

As Figure 13a shows, nearly all of the fall in factor-cost GDP is due to the reduction in capital. Labor’s contribution in the final year is a little more than -0.1 percentage point.

The ETS does induce some technological change, but its contribution to the deviation in real GDP is small. In the MMRF simulation, the carbon price leads to technological deterioration primarily through the adoption of more expensive, but less emission-intensive, production technologies (subsection 3.4). This is evident in Figure 13a for the early years of the simulation period. In the later years it is offset and eventually dominated by a compositional factor. In dynamic policy simulations, deviations in real GDP are affected by induced changes in the composition of GDP (Dixon and Rimmer, 2002, subsection 7.2). If the policy shock increases the shares in GDP of industries with rapid technological progress and reduces the shares of industries with less rapid technological progress, then real GDP growth will be elevated in the policy simulation relative to the base case.[28] In our base-case simulation, service industries are assumed to have stronger labor-saving technological progress than mining and manufacturing industries. As the carbon price shifts the composition of the

[27] The capital to labor substitution elasticity is 0.5.

[28] Similar phenomena affect the measurement of other macro indices. For example, the path of real consumption in a policy simulation can deviate from its base case path not only because of deviations in quantities consumed of each commodity but also because of deviations in budget shares.

economy towards services, this allows technological change to make a positive contribution to the deviation in real GDP from 2019 onwards.

Real GDP at market prices falls by more than real GDP at factor cost, due to a contraction in real indirect-tax bases

The percentage change in real GDP at market prices is a share-weighted average of the percentage change in real GDP at factor cost and real net-indirect-tax bases. As shown in Figure 13b, in line with the fall in factor-cost GDP, market-price GDP falls through the projection period to be 1.1 per cent below its base-case value in 2030. Box 1 provides a plausibility check on this result.

The contribution made by changes in real indirect-tax bases in 2030 is -0.3 percentage points. CO_2-e emissions, petroleum products and consumption are the principal bases on which indirect taxes are levied. All of these contract relative to their base-case values. More specifically, in 2030:

- emissions are down 25.6 per cent, contributing -0.1 percentage points to the gap of -0.3 percentage points between the deviation in market-price real GDP and factor-cost real GDP;
- petroleum usage is down 3.8 per cent, contributing -0.03 percentage points; and
- real consumption is down 1.5 per cent, contributing -0.04 percentage points.

The residual of just over 0.1 percentage points is due to changes in the miscellaneous *Other-costs* category, which is treated as an indirect tax on production for GDP accounting purposes. *Other-costs* rates in the electricity generation and supply industries are endogenous variables in the policy simulation, adjusting to accommodate changes in wholesale and retail electricity prices taken from the detailed electricity modeling (Table 3). To accommodate these changes, MMRF requires little change in the *Other-costs* rate for generation, but relatively large increases for electricity supply. MMRF does not fully capture the resource costs associated with using more expensive renewable forms of generation. Neither does it capture the impact on electricity network costs. Inputs from the detailed electricity modeling correct for this and in doing so force retail electricity prices in the MMRF simulation to increase by more than they would otherwise do in response to a carbon price. As demand for electricity falls, so does the production of the now heavily taxed electricity supply industries. This fall in the real *Other-costs* base contributes 0.1 percentage points to the overall fall in real market-price GDP.

Box 1: Check on reality via back-of-the-envelope calculations

As noted above, by 2030 with an emissions price of close to $50, real GDP at market prices is projected to be 1.1 per cent lower than it otherwise would have been and emissions are projected around 25 per cent lower.

Is this result plausible? To answer this question, CoPS modelers typically make use of back-of-the-envelope calculations. This can be done in a formal way using a stylized model as demonstrated in the Appendix. Or it can be done less formally. For example, we know that the main CO_2-e emitting activities are the fossil-fuel-based provision of electricity and transport services. According to the MMRF database, in 2011 these activities represent about 2.5 per cent of market-price GDP and about 55 per cent of total emissions.

Based on the Frontier Economics electricity model and expert transport-sector input, Australia can cut its emissions from these sectors by about 45 per cent with roughly a 55 per cent increase in the costs of electricity and motor fuels. As a back-of-the-envelope calculation, this suggests that Australia could make a 25 per cent cut in emissions at a cost of around 1.4 per cent (= 55 per cent of 2.5) of GDP. The projected outcome for real GDP is a little milder than this, suggesting that cheaper abatement opportunities exist than might be available from electricity and transport alone.

By 2030 Australia must import a significant quantity of permits to meet its global ETS obligation.

Figure 14 repeats the plots of Australia's permit allocation and base-case emissions from Figure 7 and adds a plot of emissions-permit imports from the ETS simulation. Permit imports fill the gap between the permit allocation and actual emissions under the ETS.

The permit price effectively stabilizes total emissions near to their 2010 levels. Hence, with Australia's allocation of permits progressively falling, there is an increasing need to purchase permits from overseas. In 2030, around 160 Mt of permits are required. At a price of nearly $50 per tonne, this translates into an annual financing cost of close to $8 billion.

This financing cost represents a reduction in domestic welfare in the form of a transfer to foreigners. An alternative way in which Australia might meet its emissions target would be to impose a domestic emissions tax on top of the international permit price.
This would involve a transfer of tax revenue from the domestic private sector to the Australian government - and a deadweight loss. The latter represents a reduction in domestic welfare and is additional to the loss represented by the purchase of permits from the international market under the scheme that we have simulated. Hence, relying on imported permits minimizes the global cost of abatement and the loss of domestic welfare.

The ETS reduces HDI and real private consumption, but the fall in consumption is attenuated by an increase in the APC

Figure 15 shows percentage deviations from base-case values for real private consumption, consumer-price-deflated HDI and the national average APC. In 2030, HDI is down 2.3 per cent relative to its base-case level, and real private consumption is down 1.5 per cent. The difference is due to an increase in the APC of 0.9 per cent.

The carbon charge reduces HDI by reducing the factor incomes (wages and profits, after income tax) that domestic residents receive from domestic enterprises. However, the charge does not reduce HDI by the entire amount of the gross revenue that it raises. Some of that revenue is required to purchase emissions permits from overseas but some is returned to domestic households, either indirectly *via* shielding payments that are made to domestic EITEIs or directly *via* lump-sum recycling payments. In a partial-equilibrium world, the lump-sum payments would be equal to the difference between the gross ETS revenue and the costs of shielding and international-permit purchases. But our general equilibrium calculations take account of the indirect effects that the ETS might have on the government budget balance. Lump-sum payments to households are then whatever is necessary to insulate the government budget balance (as a share of GDP) from the total effects of the ETS. The first part of Table 8 decomposes the $b change in HDI in 2030 into its components. Note that the excess of gross ETS revenue over the international permit cost is $18.1b but only $14.5b of this is returned to household *via* lump-sum payments. The reason is that the indirect effects of the ETS on the government budget are negative – the ETS reduces income-tax revenue, for example.

Recall that the APC is an endogenous variable, moving to ensure that the national balance on current account remains at its base-case level. To maintain an unchanged balance on current account, domestic savings (private *plus* public) must change to accommodate changes in aggregate investment. As shown in Table 8, the ETS generates an $18.1 billion (or 3.4 per cent) reduction in aggregate investment relative to base case. Public saving falls by $3.4 billion. Hence, private saving must fall by around $15 billion. Given a fall in total household disposable income of $29.8 billion and a base-case value for the APC of 0.78, the APC must rise to achieve the necessary change in saving.

Real gross national expenditure falls relative to real GDP leading to an improvement in the net volume of trade.

Figure 16 shows percentage deviations from base case values for real private consumption (C), real public consumption (G), real investment (I), real exports (X) and real imports (M). Deviations in C have already been discussed. Deviations in nominal G reflect deviations in nominal GDP. Real government consumption rises relative to real GDP because the price of government spending (heavily influenced by the price of labor) relative to the price of GDP moves in line with the real wage rate. Deviations in I, which as noted above are particularly sharp, reflect the declines in gross investment necessary to accommodate the falls in capital shown in Figure 12.

On balance, real gross national expenditure (= C+I+G) falls by more than real GDP, implying an improvement in the net volume of trade (X-M). This sterilizes the impacts on the current account balance of deterioration in the terms of trade and the cost of purchasing global emissions permits.

To achieve the necessary improvement in net trade volumes, mild depreciation of the real exchange rate is necessary. This improves the competitiveness of export industries on foreign markets and the competitiveness of import-competing industries on local markets. In 2030, the real exchange rate is 2.5 per cent below its base case value.

Production in some industries increases relative to base case, while production in other industries falls.

Table 9 gives percentage deviations from base-case production levels for industries nationally in 2030. There are a number of industries for which the ETS raises output significantly. The most favorably affected industry is *Forestry* (industry 7), for which the carbon charge is effectively a production subsidy on bio-sequestration. Two other industries very favorably affected are *Electricity generation - other renewable* (industry 37, rank 3) and *Electricity generation – gas* (industry 33, rank 2). The carbon price causes substitution in favor of these industries at the expense of high-emissions *Electricity generation – coal* (industry 32, rank 58). Another negative factor for coal generation is the reduction in overall electricity demand due to the increased price of electricity to final customers. In Table 9, this shows up as a decline in production in the *Electricity supply* industry (industry 38, rank 55).

Table 9 shows significant increases in production for *Iron and steel* (industry 25, rank 4) and *Alumina* (industry 26, rank 6). Both are energy-intensive and trade-exposed and under a unilateral ETS would contract, unless shielded. However, GTEM analysis of the multilateral aspects of the ETS projects trade diversion towards these Australian industries due to the availability of cheap energy-abatement options in Australia that are not matched by competing suppliers.

Another positive factor for these industries, and for all other traded goods sectors, is the projected depreciation in the real exchange rate. A lower real exchange rate means that exports of industries such as the metal producers are more competitive on world markets.

Coal (industry 8, rank 57) production is projected to fall by 12.8 per cent compared to its base-case level. The imposition of the ETS adversely affects coal demand for electricity generation and steel production in Australia and overseas. Domestic demand for coal falls by 14.6 per cent. Foreign demand, which contributes around 85 per cent to overall demand, is down 12.5 per cent. These projections are remarkably sanguine when compared to the dire predictions from coal-industry representatives. In terms of average annual growth, the projections imply a reduction from 4.0 per cent in the base case to 3.3 per cent with the ETS in place. The key factor underlying this mild outcome is rapid uptake of clean-coal technologies for electricity generation. In Australia, the new technologies are mainly based on Carbon Capture and Storage (CCS). In the rest of the world, as modeled by GTEM, the new technologies include CCS and other less radical innovations that have already started to be used in Australia.

Contraction in export demand accounts for the 5.8 per cent reduction in production of *Gas mining* (industry 10, rank 53).

Other adversely affected industries are *Private transport services* (industry 56, rank 49), *Private electricity equipment services* (industry 57, rank 56) and *Private heating services* (industry 58, rank 53). All three are affected by increases in the price of energy: automotive fuels for transport services, electricity for electrical equipment services and gas for heating services. Increased energy costs shift their supply schedules up, leading to adverse substitution in residential demand.

Most of the remaining industries suffer mild contractions in output relative to base-case levels, in line with the general shrinkage of the economy. General economic conditions are particularly influential for the service industries.

Emissions from most sources fall

Table 10 shows deviations (in percentages and Mt of CO_2-e) from domestic base-case emissions. In 2030, total domestic emissions are down by 23.6 per cent, or 181.8 Mt of CO_2-e. In addition, permits for 160 Mt of CO_2-e are imported, making Australia’s total contribution to global emissions reduction about 342 Mt of CO_2-e.

Domestic emissions from stationary energy and fugitive sources deliver the bulk of the overall abatement. Emissions from stationary energy are down 47.5 Mt relative to their base-case levels, with emissions from electricity generation down by 37.4 Mt, and emissions from other forms of direct combustion down by 10.1 Mt. Fugitive emissions fall by 41.4 per cent (28.6 Mt). Significant abatement also occurs in other areas, and in terms of percentage deviations are larger than abatement from stationary-energy and fugitive sources. From waste, emissions are down by 75.9 per cent (or 10.9 Mt of CO_2-e) relative to base-case levels, while emissions from industrial processes fall by 56.1 per cent, (or 23.1 Mt of CO_2-e).

All of the emission reductions outside of electricity and transport occur *via* reductions in the output of the relevant emitting industry or reductions in emissions intensity brought about by the price-responsive mechanisms outlined in subsection 3.4. The abatement from stationary energy and transport is achieved *via* industry activity effects, fuel switching and technology changes. The last-mentioned is most important for electricity where, according to the detailed electricity modeling, extensive abatement is achieved from the uptake of clean coal technologies, especially in the later part of the projection period.

Conclusion

In this Paper, we focus on issues that arise in using a CGE model of the Australian economy to provide advice to policy makers and other stakeholders about the effects of complex real-world policy proposals. To illustrate the issues, we use a study of the effects of the Australian government's 2008 emissions-trading policy proposal (Table 6). The proposal integrates Australia into a global trading scheme by 2015 and requires Australia to progressively reduce emissions to around 40 per cent below their base-case level by 2030. This reduction can be achieved by a mix of domestic abatement and purchases of emissions permits from the global market. The global price of permits rises from around $AUD 25 per tonne in 2015 to around $AUD 50 per tonne in 2030.

Main results

A number of key findings emerge from our simulations of the effects of the ETS policy.

1. Domestic abatement falls well short of targeted abatement, requiring significant amounts of permits to be imported. As can be seen in Figure 14, in 2030 only about half of the required reduction in emissions is met from domestic abatement, leaving half to be met from foreign-permit purchases.
2. Despite the requirement for deep cuts in emissions, the ETS reduces Australia's GDP by only just over 1.1 per cent in 2030 relative to the base case (Figure 13b). In subsection 6.1 (see especially Table 7) we discuss alternative ways in which this result can be presented.
3. The negative impact on real household consumption, which is the preferred measure of national welfare, is somewhat greater reflecting the need to import permits. The cost of imported permits reduces household income. Relative to its base-case level real household consumption is down by over 2.0 per cent in 2030 (Figure 15).
4. While the national macroeconomic impacts of the ETS are modest in the context of the policy task, this does not carry through to the industry (Table 9) and regional (Figures 20 to 23) levels.
5. Relative to base case, there are a number of industries for which the ETS significantly raises output in percentage terms. The most favorably affected industry is *Forestry*, for which the carbon charge effectively is a production subsidy. Within the electricity sector, non-hydro renewables and gas-fired generation gain at the expense of coal-fired

generation. Somewhat surprisingly, production of *Iron and steel* and *Alumina* also increase due in part to over-compensation during the transition period, and in part to GTEM projection of trade diversion in favor of the Australian industries at the expense of other suppliers.

Other adversely affected industries are *Private transport services*, *Private electricity equipment services* and *Private heating services*. All three are affected by increases in the price of energy: automotive fuels for transport services, electricity for electrical equipment services and gas for heating services.

6. The pattern of impacts on Australian regions in 2030 reflects the industry effects of the ETS. At the state/territory level, Queensland is the most adversely affected region, due to its over representation of coal and coal-fired generation, and Tasmania is the most favorably affected, due to the importance of forestry.

   Twelve (sub-state) regions are identified as particularly vulnerable in terms of potential loss of employment. These include coal-dependent regions such as Hunter in NSW, Fitzroy in QLD and Gippsland in VIC. On the other hand, eight regions are identified as potentially gaining employment. These regions generally have an over-representation of the sectors that expand due to the ETS, especially forestry and renewable electricity generation.

Including detail

In the introduction to this paper, eight questions were posed regarding the level of detail required by policy makers and other stakeholders when considering CGE-based analyses of an ETS. Our experience from the Australian study suggests the following answers.

- *At what level of detail must the stationary-energy sector be modeled for the effects of policy on its emissions to be captured adequately?* For the credibility of results, we think that very fine detail is required, especially for the electricity sector. Even the back-of-the-envelope explanation of GDP outcomes given in Box 1 relies on detailed understanding of the costs and abatement opportunities available in the future from the electricity sector. Our experience is that the required level of detail is best provided by linking with a detailed bottom-up model of the stationary energy sector.
  The alternative is to elaborate the representation of the sector inside the CGE model. While attractive from a pure theoretical point of view, this is much more difficult than our preferred option because of computational and data constraints.
- *Is it necessary to include the lumpiness of generation investment explicitly in CGE computations of the effects of climate-change policy?* The issue here is really about the timing of results. If the stakeholder is interested only in broad-based analysis of outcomes for some far-off future year, or a Net Present Value (NPV) calculation of effects across

many years, then the answer is probably no, assuming that the existing treatment of investment is realistic for the projected long-run change in capital. On the other hand, if the focus is on year-to-year changes for investment and other variables, then incorporating lumpiness does matter, as illustrated in Figures 9a and 9b and the associated commentary.

- *Concern about greenhouse-gas emissions centers on a global externality problem. Does this mean that the consequences of emissions policy can only be investigated using a global model?* Certainly for Australia, and probably for most other countries, changes in trading conditions brought about by global action on climate change will be significant and therefore should be incorporated into modeling the effects of reducing greenhouse emissions. In this Paper, we showed how this can be done *via* linking of a detailed country model with a multi-country system (GTEM). GTEM provides MMRF with a carbon price and projections of changes in Australia's trading environment for the base case and the ETS-inclusive projections.
- *In modeling the effects of an emissions policy, do we need agents with full inter-temporal optimization or will recursive dynamics do?* An ETS is normally designed to ensure a measure of certainty – there will be a non-zero carbon price after a specified date, that price will probably increase given a scheme of increasing tightness of emission allocation, during the early transition period to a multinational arrangement certain emissions-intensive trade-exposed industries will be shielded, etc. Under such arrangements, investment in industries such as electricity generation, where asset lives are very long, would be expected to change in line with anticipated future changes in permit price, rather than immediate changes post announcement. Thus a degree of forward looking expectations is important, especially in the early years of any arrangement. The modeling reported in this paper generally assumes recursive dynamics. But it does incorporate forward-looking expectations in electricity and transport *via* linking with the specialized bottom-up models that assume full inter-temporal optimization. This improves the analysis considerably, particularly for the early years.
- *What representation of a country's emissions-intensive trade-exposed industries (EITEIs) is required when early action against climate change is unilateral?* Unilateral action has the potential to disadvantage a country's EITEIs. Accordingly, nearly all such schemes specify some form of assistance or shielding during the period of transition to a fully global ETS. Modeling such assistance is necessary if realistic projections of industry output and employment are required. In the modeling reported in this Paper, a detailed representation is put in place (subsection 3.3). The influence of the associated shielding can be seen, for example, in Figure 14b where, for the early transition years to 2020 some of Australia's key ETIEIs suffer little if any production loss despite the significant direct increase in unit cost due to a domestic carbon price.
- *How should energy usage be treated in the household-consumption specification of a model to be used for the analysis of emissions policy?* As explained earlier, we think that

a traditional budget-allocation model of household demand across standard budget categories, which identify energy and energy-equipment as separate products leads to unrealistic projections of final demand for energy and equipment. Our preferred treatment allows for dummy industries that provide services of energy-using equipment to private households.

- *Can CGE modeling inform policy makers about the regional effects of emissions policy?* The answer to this question is yes, as evidenced by the discussion of regional implications in Adams and Parmenter (2013). Another related question is to what extent policy makers require projections of regional effects. Our experience of modeling the effects of an ETS in Australia, and our experience more generally across many countries is that national and regional policy makers are very concerned with the regional dimension. Much of the current discussion in Australia regarding the impacts of the proposed ETS is based about the regional implications of the ETS where the impacts, as discussed in this Paper, could be highly significant. This has had a significant impact on public opinion regarding the policy.
- *What effect will the recycling of revenue from a carbon tax or sale of permits under an ETS have on the efficiency costs of the policy and on income distribution?* Revenue can be recycled in a number of ways, such as increasing government spending or transfer payments, or reducing other existing taxes. As noted in subsection 3.3, the net welfare effects of the ETS depend on the extent to which recycling of the ETS revenue adds to or offsets the distortionary effects of the ETS charge. The double-dividend literature suggest that it is possible to recycle in such a way as achieve conventional resource-allocation gains by using the revenue to reduce existing tax distortions. Another view is that the revenue churn associated with the ETS is likely to introduce inefficiencies.

  The issues here are complex, but are crucial to an understanding of the welfare implications of an emissions policy. To deal adequately with these issues, a policy model needs to have a detailed representation of the country's fiscal system and the ability to identify the income-distribution consequences of policy options. MMRF has this facility, though little use has made of it for the study reported in this Paper. Here, it is simply assumed that any revenue from the ETS in excess of that used for buying foreign emission permits or shielding domestic EITEIs is returned to households as a lump sum payment.

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Table 1: Industries in MMRF*

Name	Description of major activity
1. Sheep & beef cattle	Primary agricultural activities related to sheep and cattle production
2. Dairy cattle	Primary agricultural activities associated with dairy cattle
3. Other livestock	Primary agricultural activities associated with other animals
4. Grains	Grains production
5. Other agriculture	Other primary agricultural production
6. Agricultural services, fishing and hunting	Provision of agricultural services, fishing and hunting
7. Forestry	Logging and forestry services
8. Coal mining	Mining of coal
9. Oil mining	Mining of oil
10. Gas mining	Production of natural gas at well
11. Iron ore mining	Mining of iron ore
12. Non-ferrous ore mining	Mining of ore other than iron
13. Other mining	Other mining activity
14. Meat & meat products	Processed food related to animal
15. Other food, beverages & tobacco	Other food and drink products
16. Textiles, clothing & footwear	Textiles, clothing and footwear
17. Wood products	Manufacture of wood (including pulp) products
18. Paper products	Manufacture of paper products
19. Printing and publishing	Printing and publishing
20. Petroleum products	Manufacture of petroleum (refinery) products
21. Basic chemicals	Manufacture of basic chemicals and paints
22. Rubber & plastic products	Manufacture of plastic and rubber products
23.Non-metal construction products	Manufacture of non-metallic building products excl. cement
24. Cement	Manufacture of cement
25. Iron & steel	Manufacture of primary iron and steel.
26. Alumina	Manufacture of alumina
27. Aluminum	Manufacture of aluminum
28. Other non-ferrous metals	Manufacture of other non-ferrous metals
29. Metal products	Manufacture of metal products
30. Motor vehicles and parts	Manufacture of motor vehicles and parts
31. Other manufacturing	Manufacturing non elsewhere classified
32. Electricity generation - coal	Electricity generation from coal (black and brown) thermal plants
33. Electricity generation - gas	Electricity generation from natural gas thermal plants
34. Electricity generation – oil products	Electricity generation from oil products thermal plants

35. Electricity generation - nuclear	Electricity generation from nuclear plants
36. Electricity generation – hydro	Electricity generation from renewable sources – hydro
37. Electricity generation – other	Electricity generation from all other renewable sources
38. Electricity supply	Distribution of electricity from generator to user
39. Gas supply	Urban distribution of natural gas
40. Water supply	Provision of water and sewerage services
41. Construction services	Residential building and other construction services
42. Trade services	Provision of wholesale and retail trade services
43. Accommodation, hotels & cafes	Provisions of services relating to accommodation, meals and drinks
44. Road passenger transport	Provision of road transport services – passenger
45. Road freight transport	Provision of road transport services - freight
46. Rail passenger transport	Provision of rail transport services – passenger
47. Rail freight transport	Provision of rail transport services - freight
48. Water, pipeline & transport services	Provision of water transport services
49. Air transport	Provision of air transport services
50. Communication services	Provision of communication services
51. Financial services	Provision of financial services
52. Business services	Provision of business services
53. Dwelling services	Provision of dwelling services
54. Public services	Provision of government and community services
55. Other services	Provision of services not elsewhere classified
56. Private transport services	Provision of services to households from the stock of motor vehicles
57. Private electricity equipment services	Provision of services to households from the stock of electrical equipment
58. Private heating services	Provision of services to households from the stock of heating equipment

* For most of the industries identified in this table there is an obvious correspondence to one or more standard categories in the Australian and New Zealand Standard Industrial Classification (ANZSIC), 2006 version. The exceptions are: industries 32 to 38, which together comprise ANZSIC 26 *Electricity Supply*; industry 53, which is equivalent to the *Ownership of dwellings* industry in the industrial classification of the official Input/output statistics; and industries 56 to 58 which relate to the provision of services from the private stocks of motor vehicles, electrical equipment (not heating) and heating equipment.

Table 2: Summary of MMRF Emissions Data for Australia, 2005-06 (Kt of CO_2-e)

	Source of Emissions (fuel and non-fuel)				
Fuel User:	Coal	Gas	Refinery	Non-fuel	Total
1. Sheep & beef cattle	0.0	1.3	1,179.6	70,179.0	71,360.0
2. Dairy cattle	0.0	0.4	483.8	9,297.0	9,781.3
3. Other livestock	0.0	0.7	192.4	2,983.0	3,176.1
4. Grains	0.0	0.8	1,650.1	2,399.0	4,050.0
5. Other agriculture	0.0	0.7	1,248.3	3,085.0	4,333.9
6. Agricultural services, fishing and hunting	0.0	1.2	1,231.2	13.0	1,245.5
7. Forestry	0.0	0.0	473.6	19,610.0	19,136.4
8. Coal mining	0.0	0.0	2,761.5	21,610.0	24,371.5
9. Oil mining	0.0	0.0	136.4	818.0	954.3
10. Gas mining	0.0	8,910	263.2	6,360.0	15,614.1
11. Iron ore mining	37.1	312.0	321.8	0.0	670.9
12. Non-ferrous ore mining	699.9	660.0	3,699.9	1,634.0	6,693.7
13. Other mining	0.0	0.0	926.4	0.0	926.4
14. Meat & meat products	78.7	83.2	21.1	0.0	182.9
15. Other food, beverages & tobacco	718.4	1,529.8	124.8	0.0	2,373.0
16. Textiles, clothing & footwear	2.8	350.3	12.8	0.0	365.9
17. Wood products	371.1	96.1	14.1	0.0	481.4
18. Paper products	606.7	682.3	17.2	704.0	2,010.3
19. Printing and publishing	13.0	174.0	32.6	0.0	219.6
20. Petroleum products	0.0	1,255.1	4,740.4	490.0	6,485.5
21. Basic chemicals	507.0	1,332.2	2,073.0	2,513.0	6,425.2
22. Rubber & plastic products	27.0	982.9	398.0	0.0	1,407.9
23.Non-metal construction products	404. 2	1,814.1	156.4	1,499.0	3,873.7
24. Cement	2,004.8	1,011.9	406.5	4,738.0	8,161.2
25. Iron & steel	3,532.0	1,295.0	170.4	8,961.0	13,958.5
26. Alumina	3,488.7	3,023.6	1,958.9	0.0	8,471.2
27. Aluminum	0.0	0.0	291.6	4,642.0	4,933.6
28. Other non-ferrous metals	1,778.1	3,380.8	481.0	0.0	5,640.0
29. Metal products	0.0	76.6	25.6	0.0	102.2
30. Motor vehicles and parts	0.0	62.1	20.5	0.0	82.5
31. Other manufacturing	97.1	228.0	73.3	674.0	1,072.4
32. Electricity generation - coal	179,163.0	0.0	0.0	0.0	179,163.0
33. Electricity generation - gas	0.0	14,573.0	0.0	0.0	14,573.0
34. Electricity generation – oil products	0.0	0.0	1,042.3	0.0	1,042.3

35. Electricity generation - nuclear	0.0	0.0	0.0	0.0	0.0
36. Electricity generation – hydro	0.0	0.0	0.0	0.0	0.0
37. Electricity generation – other	0.0	0.0	0.0	0.0	0.0
38. Electricity supply	0.0	0.0	662.6	0.0	662.6
39. Gas supply	0.0	0.0	15.5	2,132.0	2,147.5
40. Water supply	0.0	0.0	307.4	0.0	307.4
41. Construction services	0.0	159.3	1,696.7	0.0	1,856.0
42. Trade services	0.0	1,490.4	5,299.0	361.0	7,150.4
43. Accommodation, hotels & cafes	0.0	232.9	705.3	302.0	1,240.2
44. Road passenger transport	0.0	5.6	2,371.0	728.0	3,104.7
45. Road freight transport	0.0	71.5	22,468.7	0.0	22,540.3
46. Rail passenger transport	0.0	0.0	341.3	0.0	341.3
47. Rail freight transport	0.0	0.0	1,793.6	0.0	1,793.6
48. Water, pipeline & transport services	0.0	4.1	2,657.8	0.0	2,661.8
49. Air transport	0.0	0.0	5,136.3	0.0	5,136.3
50. Communication services	0.0	98.2	1,574.1	0.0	1,672.3
51. Financial services	0.0	2.3	3.2	0.0	5.6
52. Business services	0.0	262.3	1,635.9	0.0	1,898.2
53. Dwelling services	0.0	5.4	18.5	0.0	23.9
54. Public services	0.0	187.4	1,867.9	0.0	2,055.4
55. Other services	0.0	44.1	1,634.0	17,037.0	18,715.1
56. Private transport services	0.0	0.0	36,905.0	1,613.0	38,518.0
57. Private electricity equipment services	0.0	0.0	0.0	835.0	835.0
58. Private heating services	0.0	6,983.6	0.0	0.0	6,983.6
59. Residential	16.8	0.0	277.9	0.0	294.7
Total	193,546.4	51,466.3	114,000.6	145,997.0	505,010.4

Table 3: Transfer of information from *WHIRLYGIG* to MMRF

WHIRLYGIG variable	MMRF Target	MMRF Instrument
3. Sent-out generation by type and region	Sent-out generation by type and region.	Cost-neutral shifts in input technologies of the Electricity-supply industry in each state.
4. Fuel usage by generation type and region.	Fuel usage by generation type and region	Cost-neutral shifts in input technologies of the fossil-fuel generation industries.
5. Emissions by generation	Emissions per unit of fuel	Naturally exogenous.

type and region	used by fossil-fuel generation industries	
6. Capacity by generation type and region	Capital stock in use by generation type and region.	Shifts in the required rate of return on capital by generation type and region, which allows capital supply to be exogenous and set equal to achieve the targeted change in capacity (Equation (2)).
7. Wholesale electricity prices by region.	Average basic price of the output of generator industries in each region.	Equi-proportionate shifts in the price of “other costs” of each generator in a region to mimic changes in unit pure profit.
8. Retail electricity prices by region	Basic price of the electricity-supply industry in each region.	Shifts in the price of “other costs” of the electricity supply industry in each region.

Table 4: Projections for National Industry Output: Base case (average annual percentage changes, ranked)

Rank	Industry	2010 to 2030
1	37. Electricity generation – other	7.3
2	7. Forestry	7.0
3	49. Air transport	5.2
4	50. Communication services	4.6
5	52. Business services	4.6
6	10. Gas mining	4.2
7	8. Coal mining	4.0
8	33. Electricity generation - gas	4.0
9	47. Rail freight transport	3.7
10	51. Financial services	3.6
11	46. Rail passenger transport	3.6
12	13. Other mining	3.5
13	54. Public services	3.4
14	44. Road passenger transport	3.4
15	55. Other services	3.1
16	12. Non-ferrous ore mining	3.1
17	45. Road freight transport	3.0
18	41. Construction services	3.0
19	57.Private electricity equipment services	3.0
20	48. Water, pipeline & transport services	2.9
21	43. Accommodation, hotels cafes	2.9
22	53. Dwelling services	2.8
23	11. Iron ore mining	2.8
24	4. Grains	2.7
25	39. Gas supply	2.6
26	26. Alumina	2.6
27	42. Trade services	2.5
28	19. Printing and publishing	2.3
29	24. Cement	2.2
30	5. Other agriculture	2.1
31	28. Other non-ferrous metals	1.9

32	40. Water supply	1.8
33	27. Aluminum	1.8
34	56. Private transport services	1.7
35	6. Agricultural services, fishing and hunting	1.7
36	58. Private heating services	1.7
37	38. Electricity supply	1.7
38	1. Sheep & beef cattle	1.6
39	20. Petroleum products	1.5
40	23. Non-metal construction products	1.5
41	3. Other livestock	1.3
42	22. Rubber & plastic products	1.3
43	17. Wood products	1.3
44	29. Metal products	1.2
45	15. Other food, beverages & tobacco	1.1
46	14. Meat & meat products	1.1
47	25. Iron & steel	1.1
48	2. Dairy cattle	0.9
49	18. Paper products	0.9
50	9. Oil mining	0.6
51	21. Basic chemicals	0.5
52	32. Electricity generation – coal	0.4
53	30. Motor vehicles and parts	0.1
54	36. Electricity generation – hydro	0.0
55	34. Electricity generation – oil products	0.0
56	35. Electricity generation – nuclear	0.0
57	31. Other manufacturing	-0.1
58	16. Textiles, clothing & footwear	-0.8

Table 5: $C0_2$-e Emissions by Major Source Category: Base case

Average annual growth rates (%), 2010 to 2030	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	AUS
Energy sector, total	1.0	-0.1	1.8	-2.0	3.6	0.9	2.2	1.5	1.3
Fuel combustion	0.7	-0.1	1.6	-1.8	3.0	0.9	2.2	1.5	1.1
Stationary	0.5	-0.4	1.5	-3.5	3.2	1.1	2.2	1.3	0.9
Electricity generation	0.3	-0.9	1.1	-8.8	1.2	1.2	2.2	0.0	0.2
Other	0.9	0.7	2.2	-0.6	4.3	1.1	2.3	1.3	2.2
Transport	1.3	1.2	2.2	0.8	2.2	0.6	2.1	1.6	1.6
Fugitive emissions from fuels	2.4	0.5	3.3	3.6	7.4	0.5	3.1	2.1	3.3
Industrial processes	1.0	1.4	2.3	1.1	1.5	1.2	2.8	2.0	1.4
Agriculture	1.2	1.2	1.5	1.0	1.1	0.5	1.6	0.8	1.3
Waste	0.9	1.0	1.7	0.5	1.5	0.3	1.4	0.9	1.1
Forestry	na	na	na	na	na	na	na	na	na
Total	1.1	0.4	1.8	0.5	3.6	2.0	2.0	1.7	1.5

Table 5 continued on next page.

Table 5 (continued): Emissions by Major Source Category: Base case

Shares in Australia-wide total (%)	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	AUST.
2010									
Energy sector, total	20.4	20.0	19.2	3.7	10.3	0.7	1.1	0.3	75.7
Fuel combustion	17.4	19.7	17.1	3.2	9.4	0.7	1.1	0.3	68.8
Stationary	12.9	15.9	13.4	2.2	7.1	0.3	0.8	0.1	52.8
Electricity generation	9.3	12.2	9.7	1.2	3.0	0.1	0.3	0.0	35.7
Other	3.6	3.7	3.8	1.0	4.2	0.3	0.5	0.1	17.0
Transport	4.5	3.8	3.7	1.0	2.3	0.4	0.3	0.2	16.0
Fugitive emissions from fuels	3.0	0.3	2.1	0.5	0.9	0.0	0.0	0.0	6.9
Industrial processes	2.5	0.7	0.9	0.5	1.0	0.2	0.1	0.0	5.9
Agriculture	3.6	3.5	5.4	1.1	2.3	0.5	1.3	0.0	17.7
Waste	1.2	0.8	0.7	0.2	0.4	0.1	0.0	0.0	3.5
Forestry	0.2	0.8	0.0	0.3	1.2	0.3	0.0	0.0	2.8
Total	27.5	24.3	26.3	5.1	12.9	1.2	2.4	0.4	100.0
2030									
Energy sector, total	18.5	14.6	20.5	1.9	15.4	0.6	1.3	0.3	73.1
Fuel combustion	14.9	14.4	17.6	1.7	12.6	0.6	1.2	0.3	63.3
Stationary	10.5	10.8	13.3	0.8	10.0	0.3	0.9	0.1	46.8
Electricity generation	7.4	7.7	9.0	0.1	2.8	0.1	0.3	0.0	27.4
Other	3.2	3.1	4.3	0.7	7.2	0.2	0.6	0.1	19.4

Transport	4.4	3.5	4.3	0.9	2.6	0.3	0.3	0.2	16.5
Fugitive emissions from fuels	3.6	0.3	2.9	0.2	2.8	0.0	0.1	0.0	9.8
Industrial processes	2.3	0.7	1.1	0.4	1.0	0.2	0.1	0.0	5.8
Agriculture	3.4	3.3	5.4	1.0	2.1	0.4	1.3	0.0	16.9
Waste	1.1	0.8	0.8	0.1	0.4	0.1	0.0	0.0	3.3
Forestry	0.0	0.2	0.0	0.1	0.5	0.1	0.0	0.0	0.9
Total	25.3	19.6	27.8	3.5	19.5	1.3	2.7	0.4	100.0
Total emissions (Mt of CO_2-e)	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	AUST
2010	144.9	128.1	138.6	27.2	68.0	6.3	12.8	1.9	527.8
2030	179.3	138.8	197.6	24.8	138.3	9.4	18.9	2.7	709.8

Table 6: Features of the ETS scheme as modeled

Assumption	Details
Timing and relationship to global action	Scheme starts in 2011 as a domestic scheme with a specified emissions price. From 2012 to 2020 it continues to operate as a domestic scheme, but with permits allowed to be purchased from overseas such as credits generated through projects under the Kyoto Protocol's Clean Development Mechanism (CDM). From 2020 onwards, Australia's scheme is fully integrated into a single comprehensive global scheme. Scheme price is specified for each year. The allocation of permits in Australia is specified from 2012 onwards. Emission price and permit allocation come from GTEM.
Coverage	Phased coverage of sectors: • All emissions other than from agriculture and transport from 2011 onwards. • Transport emissions from 2012. • Agricultural emissions from 2015. All sectors covered by the scheme face the same emissions price.
Free permit allocation to generators	Limited free allocation of permits to electricity generators to 2020. Emission permits are allocated to offset net loss in profits.
Compensation for trade exposed, energy intensive industries	Energy intensive trade exposed industries are compensated through to 2020 according to the shielding formulae (7) and (8). Category 1 industries are: Sheep and beef cattle (industry 1), Dairy cattle (2), Grains (4), Cement (24), Iron and steel (25) and Aluminum (27). Category 2 industries are: Other livestock (industry 3), Gas mining (10), Paper products (18), Basic chemicals (21), Non-metal construction products (23), Alumina (26) and Other non-ferrous metals (28). From 2020 onwards the shielding rates decline in a linear way to zero in 2025.
Recycling of surplus revenue	Remaining permits, beyond those used to compensate generators and trade exposed energy sectors, were assumed to be auctioned, with surplus revenue recycled as a lump sum to households.

Other Australian mitigation policies	The MRET continues to operate through to 2020. Most other mitigation policies included in the base case cease with the exception of a QLD scheme designed to increase gas generation in that state to 15 per cent of total generation.
Banking	Unconstrained banking is allowed, but no borrowing. The impact of banking is reflected in the Frontier modeling for the electricity generation sector and thus influences the permit price adopted in the MMRF modeling. Banking allows arbitrage between higher permit prices later in the ETS period and lower permit prices earlier. This has the effect of increasing the amount of (cheaper) abatement undertaken early, and reducing the amount of (more expensive) abatement later.

Table 7: Alternative interpretation of ETS impacts

Equation number	*Description of measure*	2020	2030
10	Average annual growth rates (%)	2.91(Base) 2.87(ETS)	2.63(Base) 2.56(ETS)
11	Deviations from base case (%)	-0.5	-1.1
12	Absolute deviations from Base case ($m)	-7268.7	-20138.4
13	Months of growth lost due to the ETS	2.0	4.9

Table 8: Household income, consumption, savings and investment (changes from base case values, 2030)

	$b deviation
Household Disposable Income	
Household income from labor and capital after income tax	-33.4
Permit price times emissions (Gross permit tax)	26.0
Minus value of permits purchased from overseas	-7.9
Minus value of shielding	0.0*
Government handout to maintain budget balances (ex permit income)	-14.5
Total Household disposable income	-29.8
Private consumption expenditure	***-14.8***
Public consumption expenditure	***-6.3***
Private saving (ΔHDI – Δprivate consumption)	***-15.1***
Public saving (Δgovernment income – Δpublic consumption)	***-3.4***
Investment	***-18.1***

*Shielding rates decline to zero after 2020.

Table 9: National Industry Output (percentage changes from base case values, 2030, ranked)

Rank	Industry	2030
1	7. Forestry	80.2
2	33. Electricity generation - gas	15.5
3	37. Electricity generation – other	12.9
4	25. Iron & steel	9.1
5	28. Other non-ferrous metals	9.1
6	26. Alumina	6.5
7	21. Basic chemicals	3.8
8	3. Other livestock	1.9
9	46. Rail passenger transport	1.8
10	16. Textiles, clothing & footwear	1.7
11	23. Non-metal construction products	1.6
12	30. Motor vehicles and parts	1.5
13	18. Paper products	1.4
14	17. Wood products	1.2
15	22. Rubber & plastic products	1.0
16	2. Dairy cattle	0.8
17	45. Road freight transport	0.8
18	15. Other food, beverages & tobacco	0.7
19	6. Agricultural services, fishing and hunting	0.3
20	19. Printing and publishing	0.2
21	34. Electricity generation – oil products	0.0
22	36. Electricity generation – hydro	0.0
23	35. Electricity generation – nuclear	0.0
24	9. Oil mining	0.0
25	1 Sheep and cattle	-0.1
26	31. Other manufacturing	-0.1
27	29. Metal products	-0.2
28	4. Grains	-0.2

29	53. Dwelling services	-0.2
30	54. Public services	-0.2
31	51. Financial services	-0.2
32	48. Water, pipeline & transport services	-0.2
33	42. Trade services	-0.3
34	52. Business services	-0.3
35	11. Iron ore mining	-0.4
36	12. Non-ferrous ore mining	-0.5
37	5. Other agriculture	-0.6
38	50. Communication services	-0.7
39	40. Water supply	-0.8
40	14. Meat & meat products	-0.8
41	39. Gas supply	-1.0
42	55. Other services	-1.2
43	43. Accommodation, hotels & cafes	-1.6
44	13. Other mining	-1.7
45	24. Cement	-1.7
46	47. Rail freight transport	-2.1
47	49. Air transport	-2.1
48	27. Aluminum	-2.4
49	56. Private transport services	-2.4
50	44. Road passenger transport	-2.4
51	41. Construction services	-3.1
52	58. Private heating services	-4.6
53	10. Gas mining	-5.8
54	20. Petroleum products	-5.9
55	38. Electricity supply	-6.8
56	57. Private electricity equipment services	-7.7
57	8. Coal mining	-12.8
58	32. Electricity generation – coal	-18.8

Table 10: $C0_2$-e Emissions by Major Source Category for Australia (changes from base case values)

Percentage deviations from base case values	2030
Energy sector, total	-17.3
Fuel combustion	-13.6
Stationary	-14.3
Electricity generation	-19.2
Other	-7.3
Transport	-11.7
Fugitive emissions from fuels	-41.1
Industrial processes	-56.1
Agriculture	-17.6
Waste	-75.9
LUCF	na
Total	-25.6

Figure 1a: Export Response in GTEM

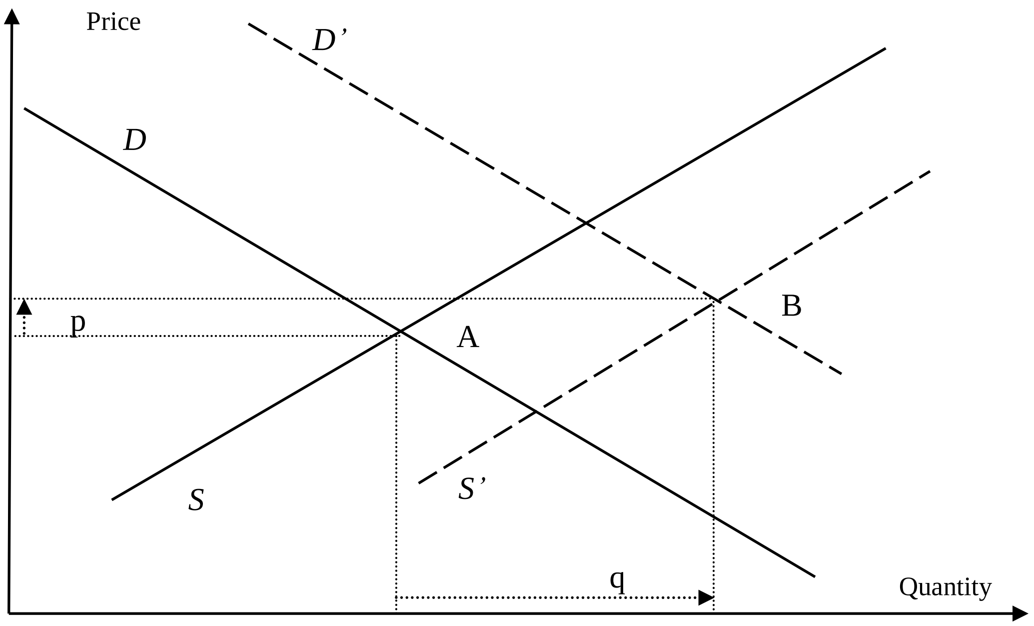


Figure 1b: Shift in export demand in MMRF

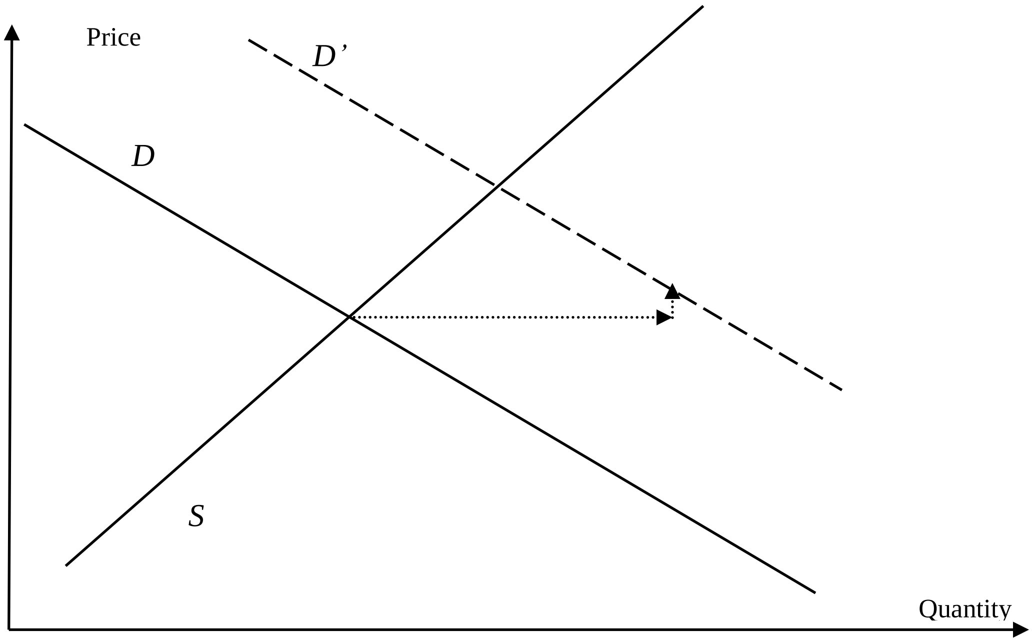


Figure 2a: Marginal abatement curve for the hypothetical industry

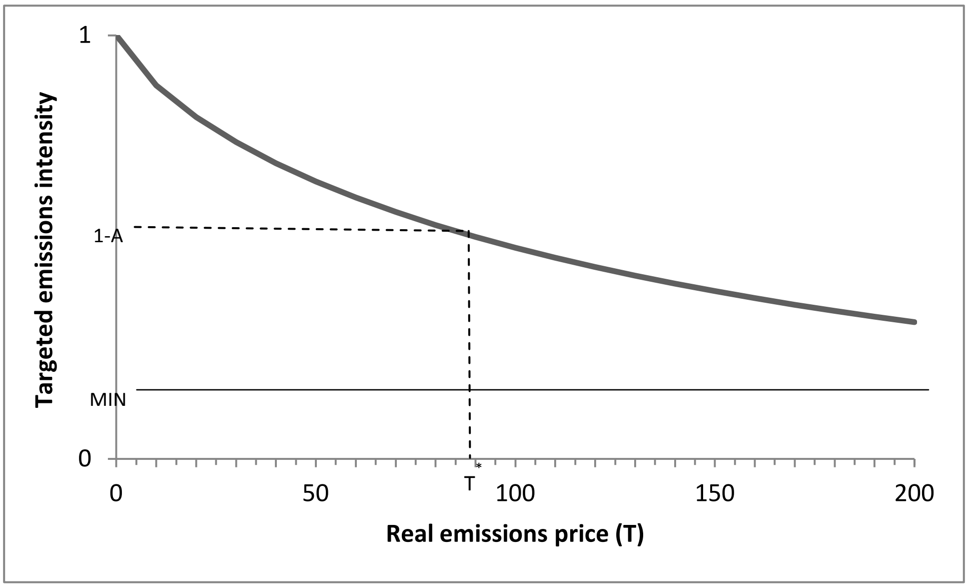


Figure 2b: Emissions intensity as a function of the real carbon price

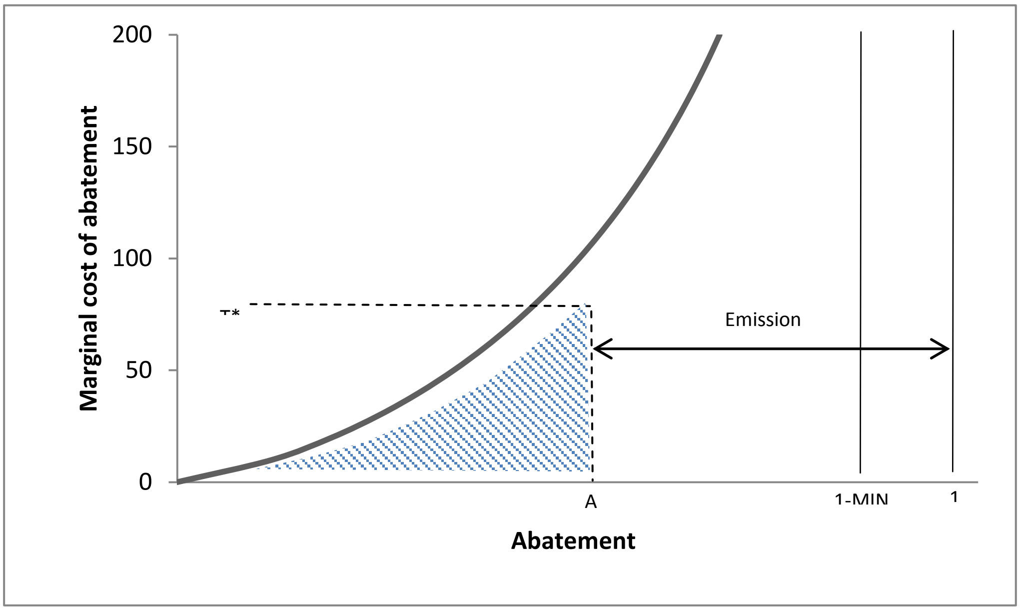


Figure 5: Emissions by major source in the base case

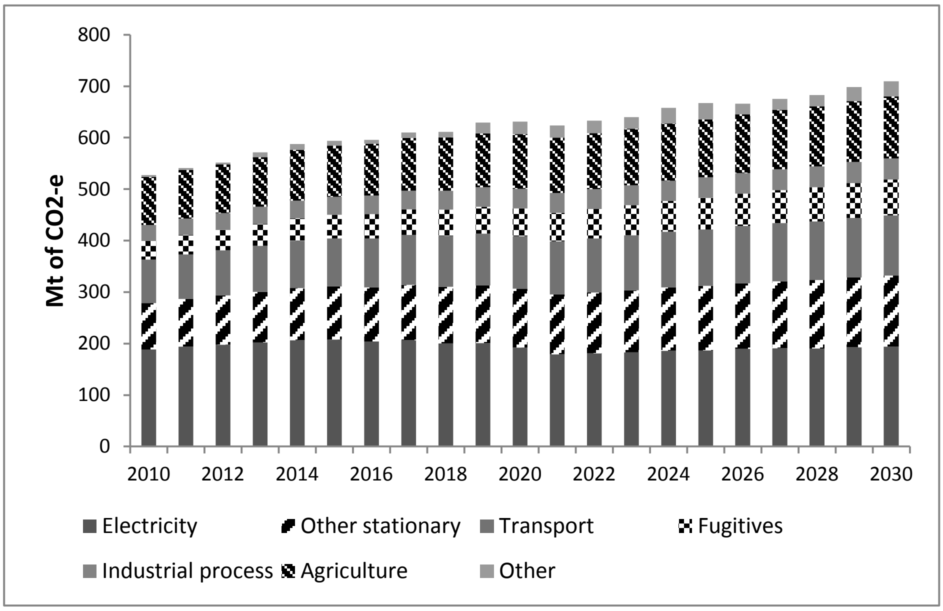


Figure 6: Price of permits in real Australian dollars

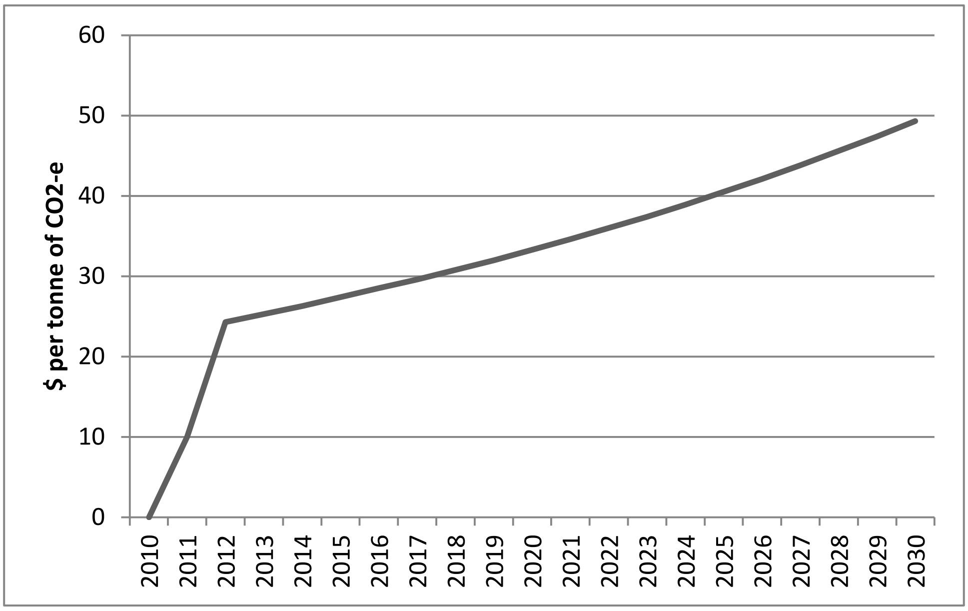


Figure 7: Permit allocation and base case path of emissions

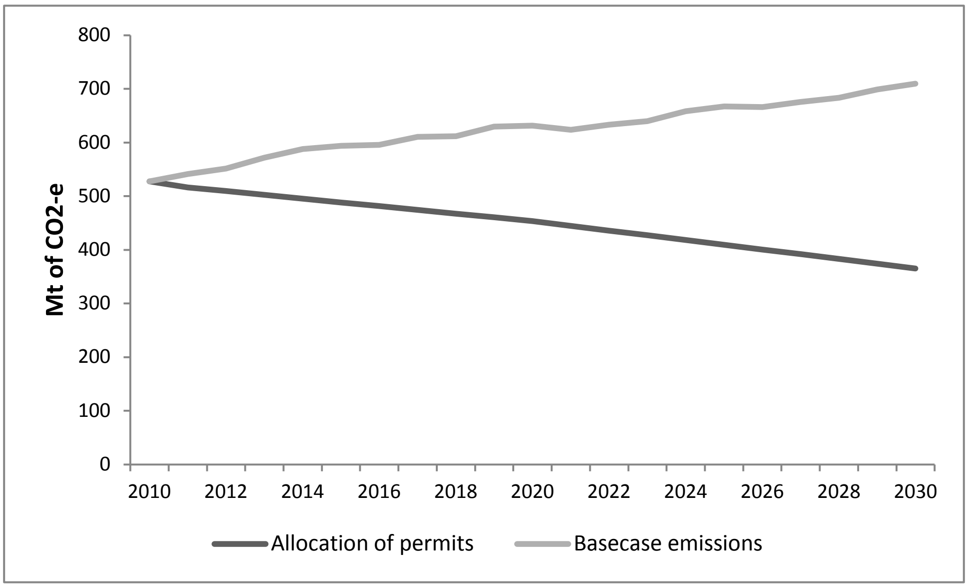


Figure 8: Forestry production and sequestration

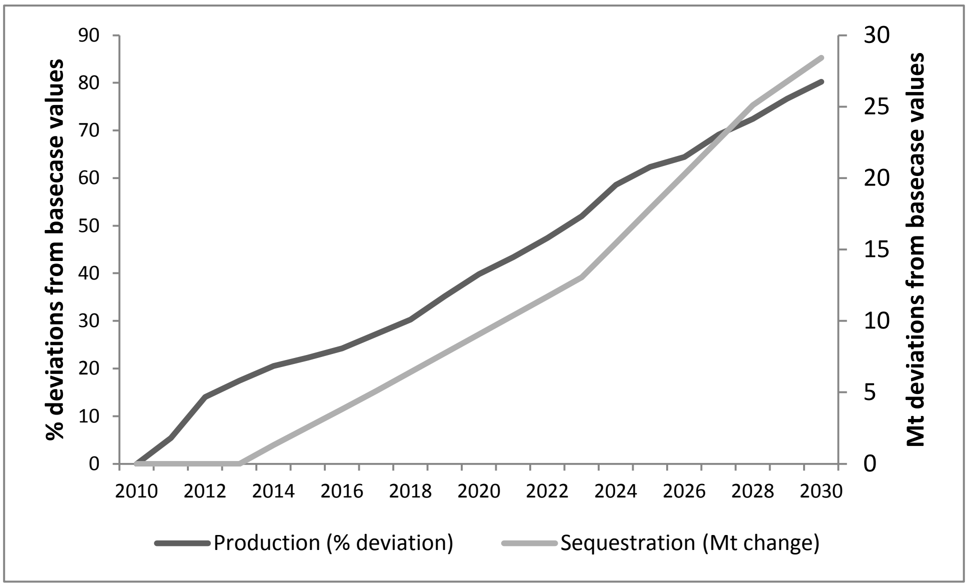


Figure 9: Australia's terms of trade

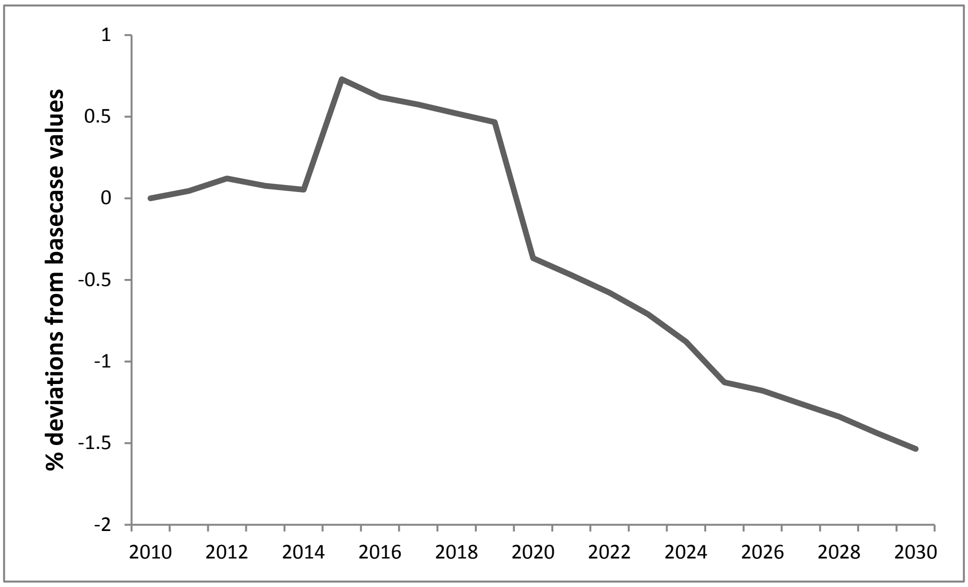


Figure 10: Interpretation of Results

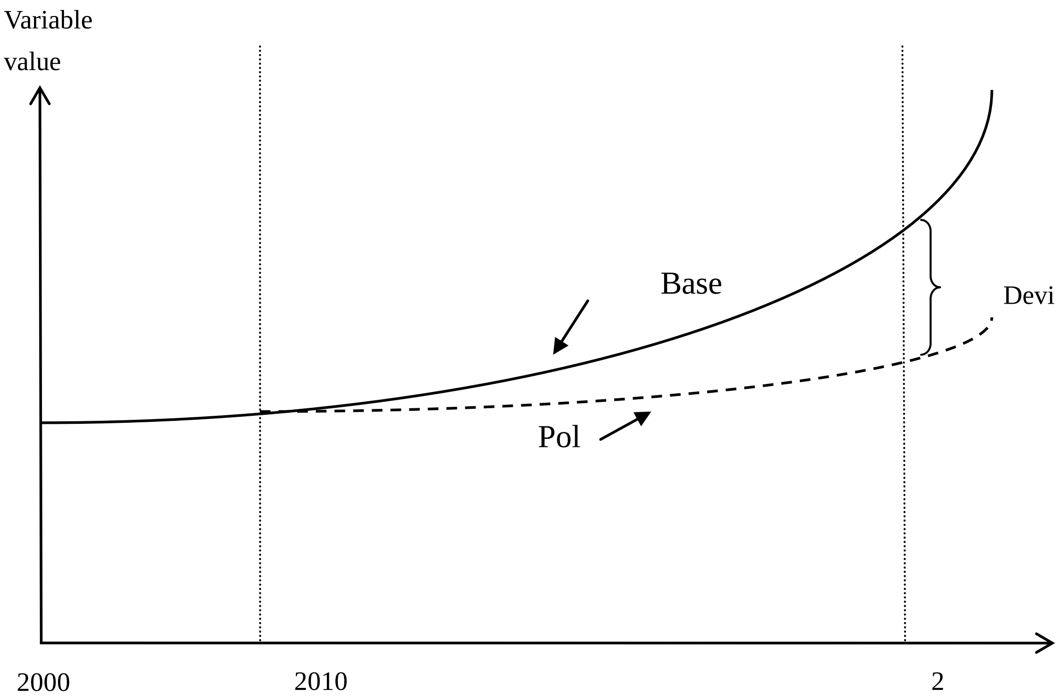


Figure 11: Deviations in employment and real wage rates

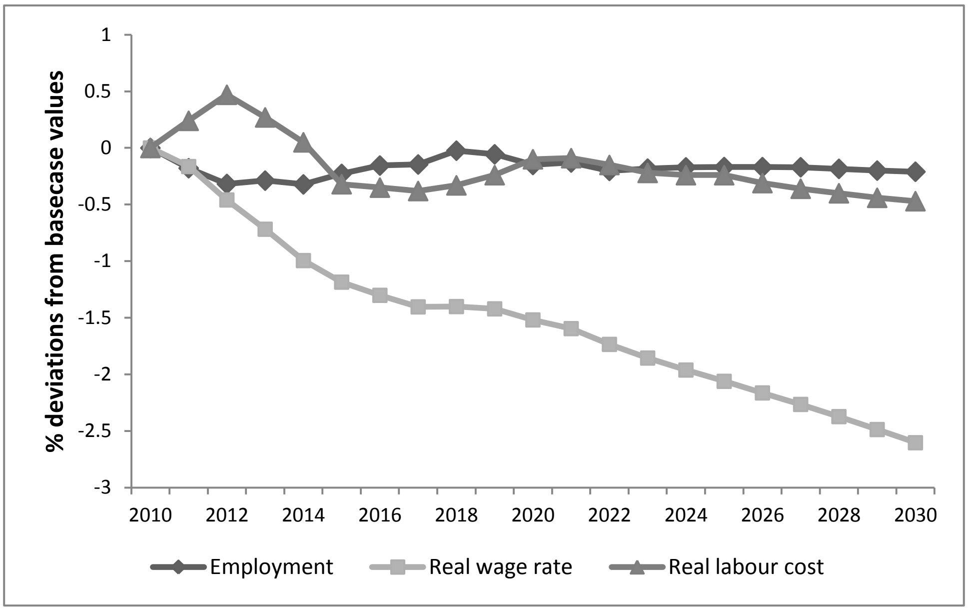


Figure 12: Deviations in capital stock and the real cost of capital

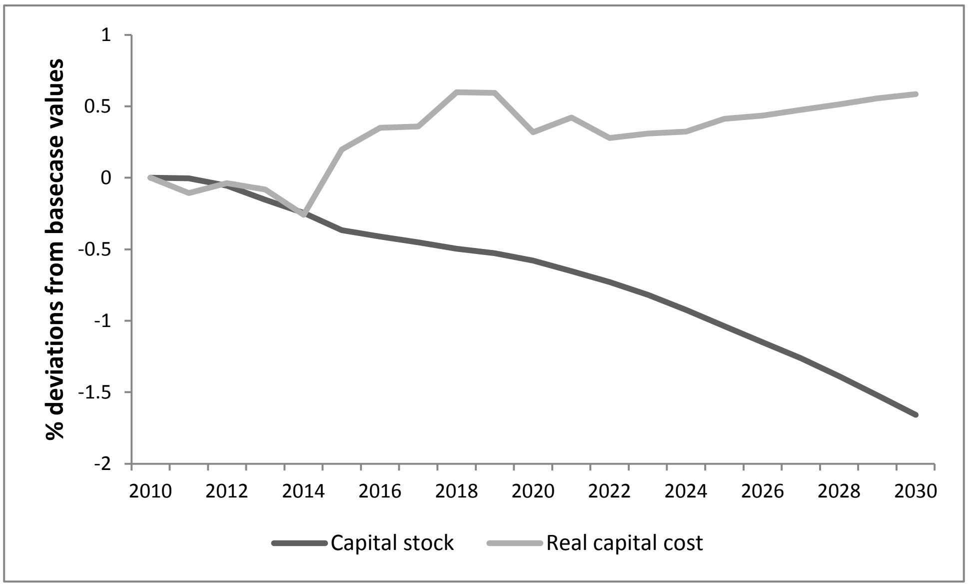


Figure 13a: Contributions to % deviation in real GDP at factor cost

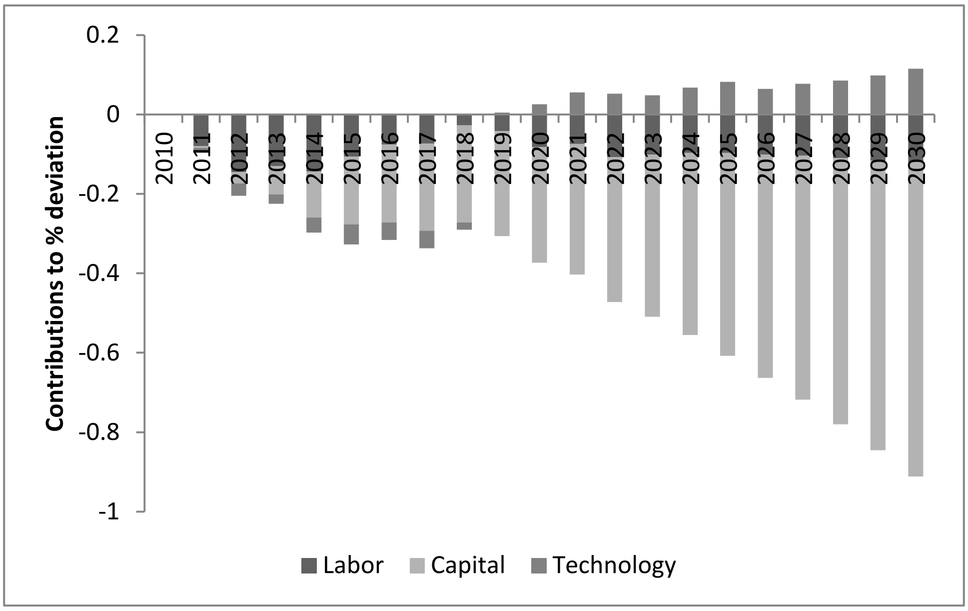


Figure 13b: Contributions to % deviation in real GDP at market prices

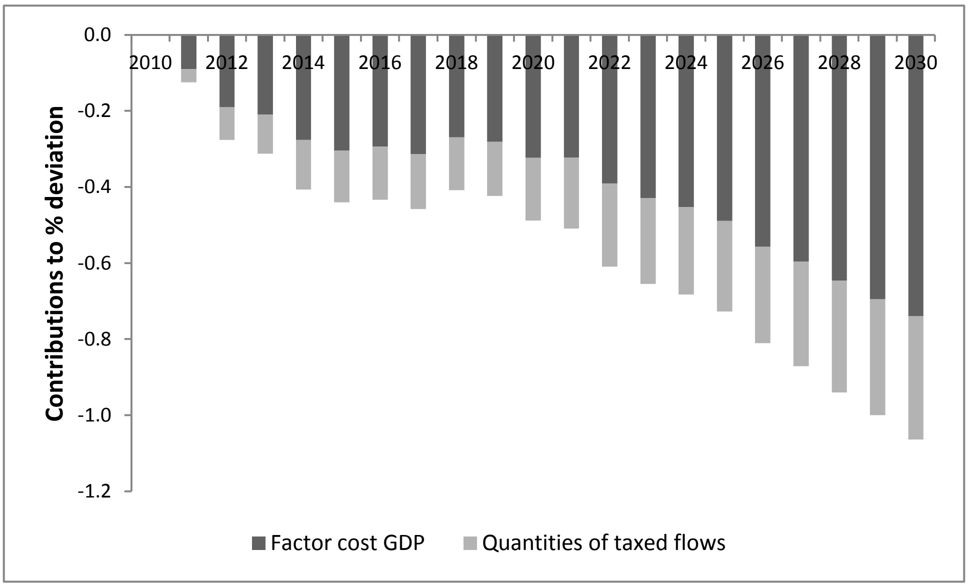


Figure 14: Emissions, permit allocation and permit imports

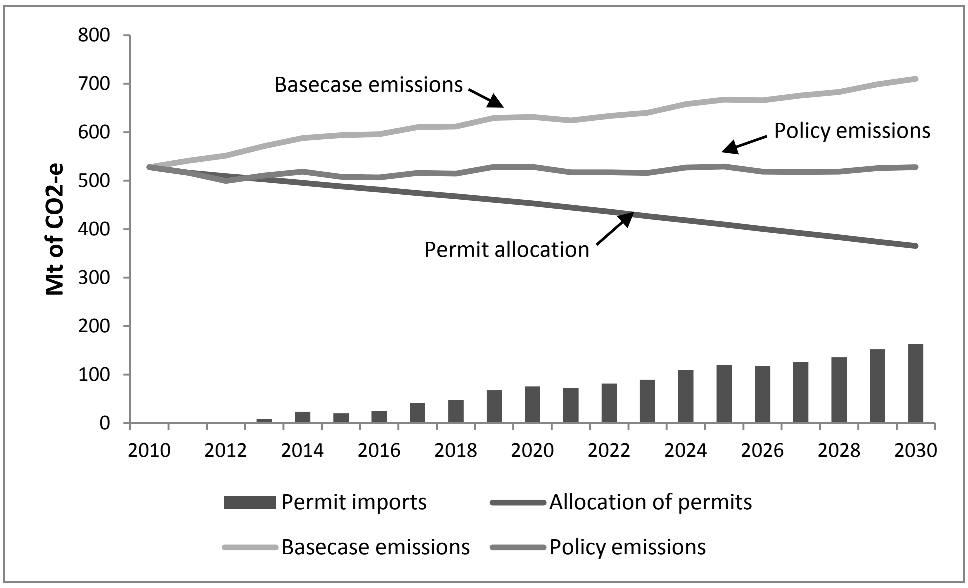


Figure 15: Real private consumption, HDI and the propensity to consume

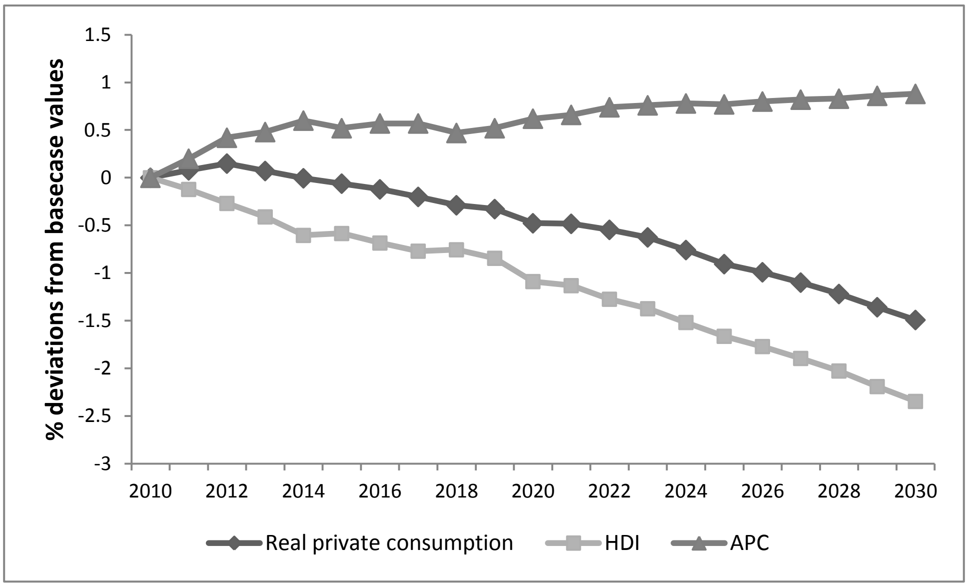
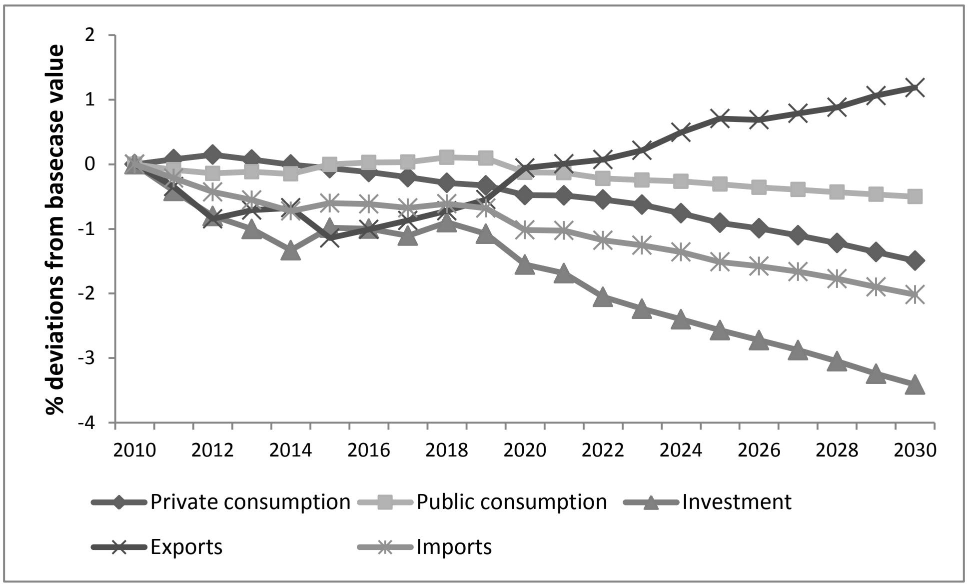


Figure 16: Deviations in main expenditure components of real GDP



Part 3: Modelling emissions trading schemes: Australia's experience and China's studies

(2) The economic impact of linking the pilot carbon markets of Guangdong and Hubei Provinces: A bottom-up China SICGE-R-CO2 model analysis[29]

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Summary

This research paper investigates the economic impact of linking China's two provincial pilot ETS markets of Guangdong and Hubei provinces, so as to gain insights into the benefits and obstacles of linking domestic carbon markets in China. The most significant benefit of linking carbon markets is derived from higher economic efficiency, as ETS schemes allow emissions abatement to be carried out in lower cost regions, which enhance the welfare of both trading parties.

The study utilized the SICGE-R-CO2 model (a bottom-up multi-regional static Computable General Equilibrium model with a carbon dioxide emission permit trading module, developed by the State Information Center under this project in cooperation with Monash University's Centre of Policy Studies), to simulate

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emissions cost reductions and the economic impact of Guangdong’s and Hubei’s independent emissions trading efforts by engaging in cross-provincial carbon trading

The analysis concluded that linking carbon trading markets in China can efficiently reduce carbon abatement costs of the regions involved. It was found that with a carbon price in Guangdong and Hubei respectively of RMB 102.9/tonne of CO2 and RMB 14.8/tonne of CO2, the average emissions reduction cost for the two regions, if the two provinces took actions independently, would be RMB 972.4/tonne of carbon dioxide. However, in a linked carbon market where Guangdong buys from Hubei 23 million tonnes of emission permits (RMB 824 million), the average carbon price would drop to RMB 35.9/tonne of carbon dioxide and the overall emissions reduction costs would be RMB 567.9/tonne of carbon dioxide (the overall efficiency gains would amount to a 41% reductions in abatement costs).

This trading scenario is based on Guangdong province’s purchase of emission permits from Hubei, as emission abatement costs in Guangdong were higher. As only 40% of emissions reductions in Guangdong were achieved within Guangdong, the province could only achieve its overall emission abatement target by purchasing 60% of its emissions permit requirements from Hubei province. This would require Hubei province to achieve an actual emission reduction which would be double that originally targeted (8.9%).

From the perspective of the industrial sector, the research found that output reductions from high emitters would be the main driving force for emissions reduction, while the substitution effect between different fuels would be limited. From a macroeconomic viewpoint, a carbon price and a carbon market would exert a modest negative impact on long term economic growth, especially on investment, but its inflation impact would be negligible. Although Hubei province’s GDP (a seller of emission permits to Guangdong) would be reduced a little, the province’s welfare component would be improved. From the perspective of specific industrial sectors, industries with high emissions such as electric power, non-metallic mineral products, non-metallic mining and dressing, metal smelting and rolling, and chemicals would be heavily impacted, but the services sector would be largely unaffected.

Inter-regional modelling research conclusions

The following conclusions can be drawn from the inter-regional modeling research:

(1) A Guangdong-Hubei linked carbon market would dramatically reduce the cost of overall regional emissions reductions. The more participants in carbon trading, the

lower the emission abatement cost would be. Therefore, it is recommended that China should actively promote regional carbon markets and list these as a key emissions reduction approach during the 12th Five-Year Plan period.

(2) Guangdong and Hubei should focus more on key industrial sectors and employ appropriate but different long-term and short-term energy efficiency and emission reduction measures. Since most carbon emissions in the two provinces are highly concentrated in certain industries, reducing emissions in these specific emission intensive industries should be considered a top policy priority by government.

In the short term, major regulatory measures should be introduced to limit the capacity of emission intensive industries, and to substitute emissions intense energy through the rapid expansion of non-fossil fuel energy sources, but these regulatory measures should play a supplementary role. In the long run, a market-based pricing mechanism for energy products should be given full play to drive restructuring of the energy mix. The regulatory measures and the pricing mechanism should complement each other.

(3) Carbon trading will have quite different impacts on the trading parties. As a buyer of emission permits, Guangdong will enjoy lower emission reduction costs in a trading scenario, while the abatement costs in Hubei will increase. Due to uneven regional development in China, emission abatement costs in enterprises in different regions will differ. Therefore, project and enterprise cooperation is recommended. Enterprises with advanced technologies and equipment and abundant capital in regions of high emissions reduction cost should be encouraged to invest in less developed areas where costs are low, which will ensure both economic development and emission reduction.

(4) Carbon markets are ultimately beneficial to industrial restructuring. Energy intensive and emission intensive industries might be affected, some severely, but the services or tertiary sector is largely unaffected. This will help adjust and optimize regional industrial structures, and transform China’s development pattern.

Future research work

In regard to future research work, it is recommended first that the State Information Center (SIC) should strengthen cooperation with regional ETS pilots, with the aim to introduce more detailed data to its SICGE-R-CO2 inter-regional model. Different types of emission permit allocation (free allocation or auction) will be evaluated, as will industrial enterprise coverage in carbon trading, making sure that an emissions cap or quota is established for each industry. Distribution of carbon trading revenue would also be examined in greater detail to determine the impact on the economy and its various sectors including renewable energy, and more actual trading and emission reduction information from pilot regions would be used to improve simulation results.

Secondly, greater in-depth investigation should be undertaken to understand the real behavior of carbon markets. This would include surveys of the seven pilot areas, to assess carbon market designs and operational features, and progress in market development.

Thirdly, international cooperation is considered necessary to allow research to have an extensive global perspective. It is the intention of the State Information Center to continue to cooperate with Monash University/Centre of Policy Studies to improve the SIC inter-regional CGE model, and to cooperate with the Australian Government and the Australian National University to learn more about the first phase of the Australian carbon market as it develops.

Fourthly, strengthened by its capacity building cooperation programs and deeper policy simulation work, SIC should be able to undertake more research and analysis of cost effective carbon markets for Chinese central government agencies, aimed at improving policy and design formulation of China's national carbon ETS market and carbon cap and pricing policy, which is due to go into operation during the 13^{th} Five Year Plan (2016-20).

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1. Research Background

Reducing greenhouse gas emission has become a consensus for countries in the world to address climate change. As the largest emitter and biggest developing country, China faces huge pressures to reduce CO_2 emissions. China puts forward the 2020 target of 40% to 45% reduction in carbon intensity against its 2005 level, and short-term targets of 16% reduction in energy intensity and 17% reduction in carbon intensity during the 12^{th} Five-Year Plan period (2011-2015). In order to achieve these goals, the 12^{th} Five-Year Plan has made clear provision for establishing and improving the statistical accounting system of greenhouse gas emissions and for setting up a carbon trading market (ETS). In 2012, seven provinces and cities[30] were listed in the pilot carbon emissions trading program. A regional-based pilot carbon market is expected to take form from 2013 and ultimately extend to cover the whole country by 2015-16. It is the first time for China that an official national policy document addressed the establishment of a national carbon market, which reflects the central government's resolution to achieve carbon abatement targets through a market mechanism. Therefore, mitigation costs of a carbon market and the potential economic influence of an ETS have become a focus of interest for government and academia.

Currently, the carbon market in China is steadily developing; however, relevant research lags far behind. Most available literature focuses on qualitative research, not quantitative calculation or estimation of economic influences. These qualitative studies fall into three categories. First, research studies about basic economic theories of carbon trading. Zheng Shuang (2007) analyzes economic principles of carbon market, its structure, and economic characteristics of international carbon market. Yang Ji (2010) focuses on basic economic theories of a carbon market, and puts forward that emission rights (permits) belong to environmental property rights, and that the motivation of carbon trading is the transaction cost. Second, studies about rules, regulations and suggestions of carbon market. After summarizing different rules for allocating emission rights, some scholars come up with their own approaches (Xu Yugao, 1997; Chen Wenying, 1998; Liu Weiping, 2004). Some other scholars have discussed potential problems and development modes of future carbon markets (Zhang Fang, 2006; Yu Tianfei, 2007; Jiang Shumin, 2009; Jiang Feng, 2009). Third, research about international practices and experience (Wang Weinan, 2009; Zhou Hongchun, 2009; Han Xintao, 2010; Zou Yasheng, 2011). Based on relevant theories about carbon trading, this kind of research draws from international experience and lessons, with the intention to provide some guidance for China.

Current quantitative researches mainly focus on the economic influences of carbon market on different countries. McKibbin (1999) utilized a global CGE model to analyze the impact of carbon trading and concluded that China would suffer the most

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[30] In January, 2012,the General Office of the NDRC issued *Notice on Carrying out Pilot Work of Carbon Emission Rights Trading*. Pilot programs would commence in seven provinces and cities (Beijing, Tianjin, Shanghai, Chongqing, Hubei (Wuhan), Guangdong (Guangzhou) and Shenzhen), and these are called “6 plus 1” pilots.

from global trading. Roman (2008) and Li Jianming (2005) employed CGE models separately to estimate the possible influence of China on European Union and Russia, and the potential of Taiwan to participate in international carbon trading. Li Na (2010) used dynamic CGE modelling of China's enormous regions to simulate the influence of uniform and differential tax rates on the regional development of China. He Jianwu and Li Shantong (2010) utilized an enormous regional CGE model to analyze the impact of uniform carbon tax rate on regional economies, industrial structures, CO_2 mitigation and regional disparities. Liang Qiaomin and Wei Yiming (2012) used CGE to analyze the distributional influence of carbon tax. Gao Pengfei, Chen Wenying and He Jiankun (2004) made detailed analysis about mitigation cost in China. In addition, using CGE, some scholars made quantitative analysis about economic influences of carbon tax (Wang Can, Chen Jining and Zou Ji, 2005; He Juhuang, Shen Keting and Xu Songling, 2002; Cao Jing, 2009; Zheng Yuxin and Fan Mingtai, 1999).

Generally speaking, there are two shortcomings in the current Chinese literature. First, most researches are qualitative; quantitative calculation is rather limited. Second, most of the available quantitative research focuses on influences of carbon trading on different countries, but not different regions within a country, let alone different provinces.

Therefore, this paper first constructs an enormous regional CGE of the year 2007, covering the 31 provinces in China. Next, a carbon price and cross-provincial carbon trading are added into the model to simulate the influence of Guangdong-Hubei carbon trading on their regional economies. Then abatement costs and the economic influence of a carbon price in a carbon market are compared.

This paper mainly answers the following questions. Will different abatement policies have different influences on regional economy? How much will this difference be? Will the abatement cost under inter-regional carbon trading be lower? What will be the influences of different polices be on different industries? Will industries with high energy consumption and high emission suffer more?

This paper is composed of five parts: first, research background; second, introduction of the model and plan; third, CO_2 emission in Guangdong and Hubei; forth, simulation results and analysis; fifth, conclusions and policy proposals.

2. Introduction of Model and Plan

(i) The SICGE-R-CO2 model

The SICGE-R-CO2 model is based on TERM[31] (The Enormous Regional Model), which was developed by the Centre of Policy Studies (CoPS) of Monash University, Melbourne, Australia. The structure is bottom-up. Each province is seen as an individual economy, and is connected with each other by inter-provincial trade, investment and labor flows. Compared with most top-down models, this model can not only analyze the influence on demand side, but also can simulate the impact on supply side. Compared with usual bottom-up structures, this model allows for re-export. This means that imported emission units are not necessarily consumed in the importing province and that exports do not always come from the exporting province. Another feature of the model is that the database is fully automatic so that addition of regions and sectors can be very flexible.

Two major improvements are made to the model. First, an updated database. The 2002 input-output table used by the original model can no longer satisfy research needs as the Chinese economy develops and the industrial structure changes. Therefore, the 2007 input-output table of 31 provinces, published by National Bureau of Statistics, was used to update the key databases. Second, CO_2 emissions were added into the model. Since most energy and environment models comprise only substitution between energy products and emission accounts of CO_2, they can only simulate impacts of changes in carbon tax and emission volume. Different from these models, carbon trading is added to analyze the influence of the inter-regional carbon market.

(ii) Simulation Plan and Policy Shock

Simulation Plan

[31] Standard TERM is an inter-regional CGE, developed by Professor Mark Horridge and Professor Glyn Wittwer of Cops at Monash University, Australia. Compared with MMRF (Monash Multi Regional Forecasting Model), TERM has a more convenient database and a faster computing speed, so it is well-received in many regions in the world. Till now, TERM has developed different versions for Brazil, Finland, China, Indonesia, South Africa, Poland and Japan.

Under the assumption that Guangdong and Hubei meet mitigation targets through the carbon market, this research discusses emission abatement costs and macroeconomic influences in different scenarios of independent abatement and common carbon market. Three simulation plans are designed. In all scenarios, an actual emission is equal to an emission permit. Of course, carbon prices of the two provinces (marginal cost of mitigation) are different under different scenarios. Under inter-provincial trading, mitigation targets can be met through both emission reduction efforts within the province and importing emission rights. Actual emission can be different from emission permit in each of the provinces, but actual emission of the whole region (Guangdong plus Hubei) must be equal to their total permit. Because of free trade between the two provinces, the price of emission rights (marginal cost of mitigation) within the region is the same. Absolute mitigation targets of Guangdong and Hubei are calculated on the basis of their carbon intensity targets during the 12th Five-Year Plan period. Detailed information can be found in the following table.

Policy Shock

The 12th Five-Year Plan sets relative carbon intensity targets for Guangdong and Hubei. However, the SICGE-R-CO2 model uses absolute mitigation numbers. So the intensity targets must be transformed into absolute ones using the following formula:

T = (BEM2015 - PEM2015) / BEM2015 (1)

T stands for absolute mitigation targets in 2015, BEM2015 for benchmark CO_2 emission, and PEM2015 for CO_2 emission in policy scenario.

BEM2015 = EM2010 * (1 + GEM)^5 (2)

EM2010 stands for CO_2 emission of 2010, and GEM for average annual growth rate of CO_2 emission during the 12th Five-Year Plan period.

PEM2015 = BGDP2015 * INTEM2010 * (1 - TINTEM2015) (3)

INTEM2010 stands for carbon intensity of 2010, TINTEM2015 for emission intensity of 2015, and BGDP2015 for benchmark absolute value of GDP.

BGDP2015 = GDP2010 * (1 + GGDP)^5 (4)

GDP2010 stands for absolute GDP of 2010, and GGDP for average annual growth rate of GDP during the 12th Five-Year Plan period.

INTEM2010 = EM2010 / GDP2010 (5)

Substitute (4) and (5) into (3), then substitute (2) and (3) into (1), and formula (6) is formed.

T = [(1 + GEM)^5 - (1 + GGDP)^5 * (1 - TINTEM2015)] / (1 + GEM)^5 (6)

As is shown in (6)[32], absolute carbon abatement targets are affected by three factors. First, the growth rate of CO_2 emission (GEM), which is positively correlated with the absolute abatement target. Second, the growth rate of GDP (GGDP), which is negatively correlated with the absolute abatement target. Third, carbon intensity target (TINTEM2015), which is in positive correlation with the absolute abatement target.

The main sources of data are as follows. The 8% and 10% average annual growth rates of GDP (GGDP) in Guangdong and Hubei (respectively) come from *12th Five-Year Plan* of the two provinces. Carbon intensity targets (TINTEM2015) come from *Working Plan of Controlling Greenhouse Gas Emissions during the 12th Five-Year Plan Period*, which was issued by State Council. The carbon intensity of Guangdong and Hubei is estimated to drop by 19.5% and 17% respectively. The growth rate of CO_2 emission (GEM) is calculated in later part of the paper. Due to the lack of CO_2 emission data of each province, we assume that the growth rate of CO_2 emission is equal to that of energy consumption. The latter can be calculated on the basis of energy consumption elasticity (energy consumption growth rate = GDP growth rate*energy consumption elasticity, under the assumption that energy consumption elasticity during the 12th Five-Year Plan period is the same as that of 2010). Energy consumption elasticity of 2010 is calculated on the basis of energy consumption growth rate and GDP growth rate in 2010. Results are shown in Table 1 and Table 2.

Table 1 Carbon emissions growth rate of Guangdong and Hubei: Baseline scenario from 2010 to 2015 (%)

	Energy consumption elasticity of GDP in 2010	GDP growth rate	Energy consumption growth rate	Carbon emissions growth rate
Guangdong	0.79	8.00%	6.35%	6.35%
Hubei	0.80	10.00%	7.97%	7.97%

Data source: calculated by the author

32 An underlying assumption in this formula is that the percentage variation of GDP before and after 2015 is minor enough to be neglected.

Table 2 Estimation of total quantity reduction target of Guangdong and Hubei in 2015 (%)

	Average growth rate p.a. GDP, 12th Five-Year Plan period 2011-2015	Average growth rate p.a. carbon emissions in the 12th Five-Year Plan period, 2011-2015	Intensity reduction target in 2015	Total quantity reduction target in 2015
Guangdong	8%	6.35%	19.5%	13.07%
Hubei	10%	7.97%	17%	8.90%

Data source: calculated by the author

According to our estimation, during the 12th Five-Year Plan period, Guangdong needs to reduce by 13.7% its carbon emission. Since emission in 2007 was 311 million tons (400 million tons in 2010[33]), Guangdong needs to reduce emissions of 40.64 million tons (52.13 million tons) by 2015. The emissions reduction target of Hubei is 8.9% in the same period. Since its emission in 2007 stands at 265 million tons (382 million tons in 2010), Hubei needs to reduce emissions of 23.62 million tons (34.02 million tons) in 2015.

(3) CO_2 Emissions in Guangdong and Hubei Provinces in 2007

(i) Emission Database

The emission database for the SICGE-R-CO2 model mainly came from 2007 input-output table of 31 provinces and 42 sectors, published by National Bureau of Statistics, and the emission factors from the UN/IPCC. Instead of emissions from end use, this database dealt with emissions from the direct production processes. Moreover, two special cases are taken into consideration. First, simple processing of energy products

33 Total energy consumption (10,000 tonnes of standard coal equivalent) can be calculated on the basis of GDP (100 million yuan) and energy intensity (standard coal/10,000 yuan) of the two provinces from 2007 to 2010. Growth rates of energy consumption of Guangdong and Hubei during the same period are 28.7% and 44.3% respectively. It is assumed that CO_2 emission grows at the same rate. Therefore, 2010 emissions of Guangdong and Hubei are 400 million tonnes (4=3.11*(1+28.7%)) and 382 million tons (3.82=2.65*(1+44.3%)).

like coal washing does not produce emissions, and is treated differently. Second, energy conversion such as the transformation from coal to coking coal involves more conversion than combustion. So the issue of combustion ratio is rather relevant, and it is the same with the transformation from crude oil into refined products. This paper used domestic research on conversion coefficients in combustion to address this issue.

(ii) CO_2 Emission of Guangdong and Hubei in 2007

In 2007, Hubei produced 265 million tonnes carbon dioxide, of which 249 million tonnes (93.8%) came from production processes. Only 6.2% came from private consumption. Coal and oil products generated a large proportion of emission (180 million tons, 69.8% and 73.25 million tons, 27.6% respectively). The 6.99 million tonnes of emission from natural gas only accounted for 2.6%. However, emissions from natural gas accounted for 32.4% of private consumption, much higher than oil products (Table 3). This is because residents rely heavily on natural gas for cooking, heating and washing in daily life.

Emissions in Hubei are heavily concentrated in the heavy chemical industry sector, with high energy consumption. The five largest emitting industries were metal smelting and rolling (50.77 million tons), production and supply of power and heat (46.55 million tons), non-metallic mineral production (42.82 million tons), chemical industries (36.71 million tons) and transportation and warehousing industries (24.74 million tons). All of these are typical energy intensive heavy and chemical industries. CO_2 emission of these five industries accounted for 81% of the total, and the share of the top ten industries reached 91%. In conclusion, CO_2 emission in Hubei is highly concentrated (Table 3).

Table 3 Carbon dioxide emissions of Hubei in 2007（unit：10 thousand ton）

Sectors	Coal	Refined oil	Natural gas	Total
Smelting and Rolling of Metals	4384.6	679.5	12.9	5076.9
Production and Supply of Electric Power and Heat Power	4635.8	14.7	4.8	4655.3
Manufacture of Nonmetallic Mineral Products	3961.5	302.2	18.5	4282.2

Chemical Industry	2712.2	931.9	27.2	3671.3
Traffic, Transport and Storage	38.8	2434.7	0.0	2473.5
Construction	279.3	348.9	0.0	628. 3
Agriculture	116.0	387.1	5.4	508.5
Hotels and Catering Services	255.4	172.8	12.7	440.9
Manufacture of Foods and Tobacco	189.5	239.0	2.2	430.7
Manufacture of General Purpose and Special Purpose Machinery	152.4	193.8	41.1	387.3
Sum of top ten(A0)	16725.5	5704.6	124.7	22554.8
Other sectors(A1)	800.8	1502.6	44.5	2347.8
Total emission from industry(A=A0 + A1)	17526.3	7207.2	169.2	24902.6
Private emission (B)	985.0	118.1	529.7	1632.8
Total (A + B)	18511.3	7325.3	698.8	26535.4

Data source：SICGE-R-CO2 database

The situation in Guangdong is similar to Hubei except for consumption (Table 4). There are two consumption differences between Guangdong and Hubei. First, Guangdong is a developed province in the southeast coastal area, with its per capita income twice as much as that of Hubei[34]. High income has driven the demand for cars and oil products. Of private consumption of Guangdong, 8.97 million tonnes CO_2 emissions came from oil products, while the amount for Hubei only stands at 1.18 million. In contrast, Hubei consumed more coal than Guangdong (Hubei, 9.85 million tonnes; Guangdong, 5.671 million tonnes) since many Hubei households depend on coal for cooking and heating. Second, high household consumption in Guangdong has led to larger emission. In 2007, emission from private consumption in Hubei only totaled 6.99 million tons, while that of Guangdong reached 32.5 million, 4.7 times as large. In addition, higher consumption emission in Guangdong had contributed to larger total emission. In 2007, total consumption in Guangdong reached 311 million tonnes, higher than that of Hubei by 45.26 million tonnes. 70% is generated from consumption.

[34] Per capita GDP (current price) of Guangdong and Hubei was RMB 33,151 and RMB 16,206 respectively. The national average is RMB 20,169: *2008 China Statistical Yearbook*.

Table 4 Carbon dioxide emissions of Guangdong in 2007（unit：10 thousand ton）

Sectors	Coal	Refined oil	Natural gas	Total
Production and Supply of Electric Power and Heat Power	11514.8	1205.2	150.7	12870.8
Manufacture of Nonmetallic Mineral Products	2711.5	412.8	462.4	3586.7
Chemical Industry	530.7	1290.5	662.7	2483.9
Smelting and Rolling of Metals	1540.0	354.0	213.5	2107.5
Traffic, Transport and Storage	0.9	1988.0	0.3	1989.2
Papermaking, Printing and Manufacture of Articles for Culture, Education and Sports Activities	1091.1	92.1	43.6	1226.9
Manufacture of Textile	514.0	72.4	25.3	611.8
Manufacture of Foods and Tobacco	375.8	54.3	19.8	449.9
Extraction of Petroleum and Natural Gas	73.4	340.3	0.6	414.3
Manufacture of Textile Wearing Apparel, Footwear, Caps, Leather, Fur, Feather(Down) and Its products	52.7	201.1	134.1	387.9
Sum of top ten(A0)	18405.0	6010.6	1713.2	26128.7
Other sectors(A1)	374.7	1558.0	673.4	2606.1
Total emission from industry(A=A0 + A1)	18779.7	7568.6	2386.5	28734.9
Private emission (B)	567.1	896.7	863.3	2327.0
Total (A + B)	19346.8	8465.3	3249.8	31061.9

Data source：SICGE-R-CO2 database

4. Results and Analysis

(i) Distribution of Emission Reductions

Table 5 shows the distribution of emission reductions in different scenarios (Simulation 1, Simulation 2 and Simulation 3). If the province works independently, all reductions are carried out within the province. If inter-provincial trading is allowed, mitigation targets can be achieved through both "domestic mitigation" and "purchase of emission rights". Negative value under domestic mitigation stands for emission reductions within the province, and negative (positive) value under purchasing emission rights stands for seller (buyer) of emission rights. The sum of these two values should be equal to the abatement target.

Table 5 demonstrates that if no link is allowed, Guangdong and Hubei can only achieve their 13% and 8.9% emission reduction targets within their respective territory. In the linkage scenario, Guangdong will buy emission rights from Hubei, as abatement cost in Guangdong is higher. Of the 13% reduction target of Guangdong, 5.7% is carried out within Guangdong and 7.3% is achieved through purchased emission units. The actual emission reduction of Hubei will reach 17.5%, 8.6% higher than the 8.9% target. The surplus would be exported to Guangdong. In a word, carbon trading will create a new approach for the two provinces in reducing emissions.

Table 5 Carbon dioxide emissions reduction and emissions right price of Guangdong and Hubei in different ways in Twelfth Five-Year period

Reduction method and price	Simulation 1 (no link）	Simulation 2 (no link）	Simulation 2（link）	
	Guangdong	Hubei	Guangdong	Hubei
Reduction by itself (%）	-13	-8.9	-5.7	-17.5
Buying emission right (%）	0	0	-7.3	8.6
Emissions right price（RMB/tonne of CO2）	102.9	14.8	35.9	35.9

Data source：SICGE-R-CO2 simulation result

(ii) Price of Emission Rights (Marginal Cost of Abatement)

As is shown in Table 5, the price in Simulation 2 (Independent mitigation of Hubei) is only RMB 14.8/tonne of carbon dioxide, the lowest in three scenarios. Since Hubei's 8.9% abatement target is lower than Guangdong's 13%, abatement cost of Hubei will be consequently lower[35]. The price of emission rights in Guangdong (Simulation 2) is RMB 102.9/tonne of carbon dioxide, which is higher than that of Hubei. In Simulation 3 (Guangdong-Hubei carbon market), the price is RMB 35.9/tonne of carbon dioxide. Therefore, the carbon market can effectively reduce the marginal cost of abatement (price of emission rights) of the whole region, which is an important guidance for policy development. In theory, the more participants in carbon trading, the lower the marginal cost of abatement will become.

(iii) Average emissions reduction cost

Table 6 shows the average emissions reduction cost of Guangdong and Hubei, which is used to estimate the consequent economic loss (actual GDP loss and cost (income) of buying (selling) emission rights).

Generally speaking, the carbon market can reduce average cost of the whole region (Guangdong and Hubei). In the no link scenario, average emissions reduction cost of the region is RMB 972.4/tonne of carbon dioxide, while in the trading scenario the cost drops to RMB 567.9/tonne of carbon dioxide. The emissions reduction cost of each tonne of carbon dioxide reduces by RMB 404.5, a 40% decrease. Therefore, the linked Guangdong-Hubei carbon market can dramatically reduce the average abatement cost of the whole region.

The emissions reduction costs of the two provinces are sharply different. If linking is allowed, the average cost in Guangdong will drop from RMB 1342.7/tonne of carbon dioxide to RMB 479.14/tonne of carbon dioxide, which is lower than the regional average of RMB 567.9/ tonne of carbon dioxide. In the linked scenario, part of the reductions in Guangdong are achieved through imported emission rights, and the ratio of domestic abatement decreases from 13% to 5.7%, so actual loss of GDP is reduced

[35] Generally speaking, the marginal abatement cost is determined by two factors. First, the economic structure, such as the ratio of energy intensive and emission intensive industries. Second, the mitigation target. Ambitious targets entail higher abatement costs.

too. In general, the reduced GDP loss is larger than the cost of purchasing emission costs, so inter-provincial carbon trading will help reduce abatement cost for Guangdong. However, it is quite different for Hubei, where the cost of abatement, if trading is conducted, will increase from RMB 310.5/tonne of carbon dioxide to RMB 706.3/tonne of carbon dioxide, which is higher than the regional average of RMB 567.9/tonne of carbon dioxide. There are two reasons for this. First, the abatement cost of Hubei is relatively low, so Hubei would reduce more emissions than required by the target in order to sell some emission rights (Table 6). Second, in the trading scenario, the price of each tonne of CO_2 emission will increase dramatically from 14.8 RMB/tonne of carbon dioxide to 35.9 RMB/tonne of carbon dioxide. Although Hubei gets some income from carbon trading, it's not enough to compensate for the loss incurred in the whole economy.

Table 6 Average cost of carbon dioxide emissions reduction in Guangdong and Hubei using different methods in the Twelfth Five-Year period[36]

	Guangdong		Hubei	
	No link	Link	No link	Link
(1）Total reduction cost（RMB million）	54513.5	19450.8	7328.9	16668.4
Real GDP loss	54513.5	18626.5	7328.9	17492.7
Expenditure for buying emission right	0.0	824.3	0.0	824.3
(2）Total CO2 emission reduction million tonnes）	40.6	40.6	23.6	23.6
Self-abatement	40.6	17.6	23.6	46.6
Purchased-abatement	0.0	23.0	0.0	-23.0
(3）Average abatement cost (RMB/tonne of carbon dioxide）	1342.7	479.1	310.5	706.3
(4）Carbon trading area (Guangdong and Hubei）	No link			Link
Average abatement cost	972.4			567.9

36 This table has four components: first, total abatement cost, including actual GDP loss and cost of purchasing emission rights; second, abatement amount, including domestic mitigation and imported emission units; third, average abatement cost of each province (total provincial cost/abatement amount); forth, average abatement cost of the whole region (total regional cost/regional abatement amount).

（RMB/tonne of carbon dioxide）

Note： Positive emissions purchase expenditure represents purchasing emissions right, Positive emissions purchase expenditure represents selling emissions right.

Data source：SICGE-R-CO2 simulation result

(iv) Abatement in Different Industries

Since most emissions of Guangdong and Hubei come from industries, it is necessary to make some detailed analysis about the key industries.

Hubei needs to reduce 23.62 million tons of CO_2 to meet its target in the 12th Five-Year Plan. Most reductions come from industries (21.15 million tons, 89.6%), and only a small part from private consumption (2.47 million tons, 10.4%). As is shown in Table 7, 97 % industrial reductions (20.50 million tons) are concentrated in the top ten emitting industries. Therefore, a clear analysis of these ten industries will ensure a comprehensive understanding of Hubei’s mitigation.

Industrial emission reductions are usually conducted in two ways: reducing output (output effect) and replacing energy products (substitution effect). First, the output effect. Reduced output would lead to smaller energy demand, which will decrease carbon emissions. Second, the substitution effect. A carbon price or a market-based abatement mechanism will lead to changes in relative prices of different energy products, which will contribute to substitution between energy products. Since different energy products have different emission intensities, substitution effect will indirectly reduce total emissions of industries.

As can be seen in Table 7, output effect will generate 12.15 million tons reductions (59% of the total 20.25 million tonnes) in the top ten industries of Hubei, while the substitution effect contributes 8.35 million tonnes (41%). The former is slightly larger than the latter. Therefore, emission reductions of Hubei will mainly come from reduced output of energy intensive industries.

However, it is not the same for every single industry. The substitution effect takes the dominant role in 5 industries, including metal smelting and rolling, chemical industry, construction industry, accommodation and catering industry, and food manufacturing and tobacco processing. In particular, the substitution effect takes a much more critical role than output effect in the last two industries. It should be pointed out that output and the substitution have opposite effects in agriculture. On one hand, increased output will lead to higher emission (output effect). On another hand, since agricultural activities rely more heavily on coal than natural gas and oil products, a carbon price will motivate more use of natural gas and oil products. So changes in energy structure will reduce emissions (substitution effect).

Table 7 Hubei carbon emissions in different scenarios in 2007 (unit: ten thousand tonnes)

Sectors	Base-line	Emission reduction in link scenario				Link scenario
		Output effect	Substitution effect	Total reduction	Surplus	Total reduction
Smelting and Rolling of Metals	5076.9	-324.4	-390.3	-714.8	4362.1	-1364.8
Production and Supply of Electric Power and Heat Power	4655.3	-357.1	-79.3	-436.3	4219	-934.5
Manufacture of Nonmetallic Mineral Products	4282.2	-338.3	-86.9	-425.2	3857	-900.2
Chemical Industry	3671.3	-134.4	-167.1	-301.5	3369.8	-618.6
Traffic, Transport and Storage	2473.5	- 35.4	-0.8	-36.2	2437.3	-84.4
Construction	628.3	- 12.8	-22.3	-35.1	593.2	-72.1
Agriculture	508.5	2.1	-3.1	-1.0	507.5	-1.9
Hotels and Catering Services	440.9	-4.5	-75.9	-80.5	360.4	-120.0
Manufacture of Foods and Tobacco	430.7	-1.3	-6.0	-7.3	423.4	-15.9
Manufacture of General Purpose and Special Purpose Machinery	387.3	-9.3	-2.9	-12.2	375.1	-26.9
Sum of top ten	22554.8	-1215.4	-834.7	-2050.1	20504.7	-4139.5

Data source：SICGE-R-CO2 database

Guangdong needs to reduce by 40.64 million tonnes of CO_2 to meet its target in the 12^{th} Five-Year Plan. Most reductions will come from industries (36.18 million tonnes), and only a small part from private consumption (4.46 million tons). As can be seen in Table 8, emissions in Guangdong are also rather concentrated in certain industries. So the top ten industries will be discussed in detail.

Different from Hubei, the output effect takes an absolutely dominant role in the top ten industries. 71% of the total of 33.77 million tonnes reductions are achieved through the output effect (23.81 million tonnes), and the rest 29% (9.96 million tonnes) by the substitution effect. However, this is not the case with every industry. The substitution effect plays a critical part in six industries, including metal smelting and rolling, chemical industries, textile, paper-making and printing, clothes, leather and down manufacturing, and food manufacturing and tobacco processing industries. Over 80% reductions of the last three industries benefit from the substitution effect. But since these three industries take only a small proportion of total abatement, the output effect is still dominant in general.

Table 8 Guangdong carbon emissions in different scenarios in 2007 (unit: ten thousand tonnes)

Sectors	Base line	Emission reduction in link scenario				Link scenario
		Output effect	Substitution effect	Total reduction	Surplus	Total reduction
Production and Supply of Electric Power and Heat Power	12870.8	-1567.7	-259.2	-1826.9	11043.9	-692.0
Manufacture of Nonmetallic Mineral Products	3586.7	-430.8	-212.6	-643.3	2943.4	-278.6
Chemical Industry	2483.9	-97.6	-130.8	-228.4	2255.5	-91.4
Smelting and Rolling of Metals	2107.5	-153.0	-163.8	-316.8	1790.7	-128.6
Traffic, Transport and Storage	1989.2	-58.3	-1.5	-59.8	1929.4	-20.6
Papermaking, Printing and Manufacture of Articles for Culture, Education and Sports	1226.9	-36.6	-126.0	-162.6	1064.3	-72.3

Activities						
Manufacture of Textile	611.8	-14.5	-28.3	-42.8	569	-17.1
Manufacture of Foods and Tobacco	449.9	-6.6	-29.8	-36.4	413.5	-15.3
Extraction of Petroleum and Natural Gas	414.3	-12.7	-0.2	-12.8	401.5	-4.4
Manufacture of Textile Wearing Apparel, Footwear, Caps, Leather, Fur, Feather(Down) and Its products	387.9	-3.2	-43.6	-46.8	341.1	-24.2
Sum of top ten	26128.7	-2380.9	-995.9	-3376.8	22751.9	-1344.4

Data source：SICGE-R-CO2 database

Due to space constraints, emission changes of the two provinces in trading scenario are not discussed here. In fact, carbon trading will only lead to fewer emission reductions in Guangdong and more in Hubei, without substantial structural changes.

(v) Macroeconomic Influence

Linked carbon trading market will impose more negative influence on the GDP of Hubei than Guangdong (Table 9). But Guangdong will suffer more in a no linked scenario, where the GDP of Guangdong and Hubei will reduce by 2.13% and 1.13% respectively. This is because the larger share of energy intensive industries and more ambitious abatement target have increased the marginal cost of abatement in Guangdong. When Guangdong purchases emission rights from Hubei to relieve abatement pressure, its GDP will only drop by 0.76%. However, Hubei’s GDP will drop by a larger number of 2.57% since the impact of excessive mitigation cannot compensate the income from selling emission permits.

A linked carbon trading market will improve the welfare for the residents in both Guangdong and Hubei. Although Hubei’s GDP will suffers losses in a linked carbon trading market, consumption will increase from -0.05% to 0.02%. Since revenues from the carbon price and emission rights improve residents’ income, consumption will consequently increase[37]. Guangdong's consumption will also rise in a linked carbon trading market from -0.31% to -0.19%. Although subsidies for residents will decrease in Guangdong, purchased emission rights will help create more jobs (no link, -1.40%; link, -0.48%). As the positive influence of employment exceeds that of subsidies, welfare for Guangdong will also improve.

All macroeconomic indicators (except for consumption) of Hubei will worsen in the linked scenario, while Guangdong has a totally different situation where all indicators improve. The following part will focus on explaining the common logic in three Simulations. As the results show, the carbon market will increase prices of energy products (electricity price in particular), and other prices will rise accordingly, so CPI will rise slightly. The carbon price will increase the cost of business, and ROI will decrease accordingly (especially for capital intensive high emitting industries), so investment and capital will all worsen. Compared to provinces without abatement tasks, real wages decrease, so some labor force will migrate to provinces without abatement tasks. And then employment will drop in abatement regions. However, the spillover effect of labor force to the non-abatement provinces is positive. Increased prices make commodities less competitive in international markets, so exports will suffer. Decreased imports results from contracted demand of the whole economy.

Table 9 The macroeconomic influence of carbon trading market in Guangdong and Hubei (%)

	Guangdong		Hubei	
	No link	Link	No link	Link
GDP	-2.13	-0.76	-1.13	-2.57
Private consumption	-0.31	-0.19	-0.05	0.02
Investment	-3.41	-1.27	-1.93	-4.29
Export	-0.74	-0.23	-0.64	-1.39
Import	-1.57	-0.57	-1.74	-3.92
CPI	0.37	0.11	0.09	0.17
Employment	-1.40	-0.48	-0.52	-1.15
Capital	-2.74	-1.01	-1.75	-3.92

Data source：SICGE-R-CO2 simulation

[37] TermCo2 assumes that the government balance sheet remains the same and that all carbon revenue is used for direct subsidy for consumers. Of course, there are also other possible assumptions such as reducing indirect consumption tax, reducing tax on new energies and balancing government account. But it is believed that direct subsidies for consumers are more realistic.

(vi) Impact on Industries

Table 10 shows changes of industrial output and emission intensity in different scenarios. Industries in Guangdong suffer less in the linked scenario, but it is the opposite for Hubei. It is found out that in different situations development trends are quite similar. Simulation results reveal that most industries are negatively impacted and the degree of impact is in positive correlation with CO_2 emission intensity[38]. Some emission intensive industries are severely affected, such as power, non-metallic mineral products, metal smelting and rolling and chemical industries.

There are also some industries whose emission intensities are not consistent with output changes. Some industries with low energy intensity suffer greater output loss. These industries include construction, real estate, metal mining and dressing, supply of natural gas and water and some other service industries in Guangdong. According to different courses, these industries can be divided into three categories.

First, reduced macroeconomic demand (income effect). Take Guangdong’s construction sector for example, which is taken as investment goods in most cases. Since total investment decreases in this region, demand for construction also falls. Meanwhile, decreased consumption lead to reduced output in other service industries, of which more than a half comes from private consumption. The share of private consumption and investment in Guangdong’s real estate reaches 60% and 17% respectively, so these two factors have imposed quite a shock.

Second, the domino effect of the industrial chain. 70% output of the metal mining and dressing industry in Guangdong is used for metal smelting and rolling. So the demand of the latter industry has a direct influence on the former one. Since metal smelting and rolling is quite energy intensive, emission reduction reduces quite a share of its output. Therefore, decreased output in the downstream industry (metal smelting and rolling) will lead to less demand for upstream production (metal mining and dressing).

Third, the substitution effect. Since Guangdong’s natural gas and water are mainly supplied to other provinces, increased prices resulting from the carbon price will make these products less competitive in the competition with other provinces. Moreover, they may be replaced by less expensive supply from other regions.

[38] CO_2 emission intensity (tonne/RMB 10,000) = total output value / total CO_2 emissions

There is an emissions intensive industry which suffers little output loss, such as the transportation and warehousing sector of Hubei. They are not for direct use, but for inter-regional trade flows. Simulation results show that the decrease in trade flow is minor, so carbon price will have little impact on the output of enterprises in this sector.

In addition, not all industries are negatively affected, and even some enjoy moderate output increase. Agriculture, education and public administration in Guangdong will benefit, as they barely consume energy products. On another hand, abatement efforts will reduce the labor price, so these labor intensive sectors will benefit. It is the same for agriculture and public management in Hubei.

Table 10 The influence of different carbon emission reduction policy on the industrial output of Guangdong and Hubei

	Guangdong			Hubei		
	Emission intensity (tonne/ RMB 10,000)	No link (%)	Link （%）	Emission intensity (tonne/ RMB 10,000）	No link (%)	Link (%)
Agriculture, Forestry, Animal Husbandry & Fishery	0.071	0.86	0.28	0.221	0.41	0.92
Mining and Washing of Coal	0.000	-0.77	-0.74	0.929	-1.77	-4.37
Extraction of Petroleum and Natural Gas	0.952	-3.06	-1.04	1.868	-0.78	-1.87
Mining of Metal Ores	0.218	-5.42	-1.99	1.773	-3.21	-7.30
Mining and Processing of Nonmetal Ores and Other Ores	4.751	-12.66	-4.82	1.704	-2.59	-5.95
Manufacture of Foods and Tobacco	0.278	-1.47	-0.53	0.577	-0.31	-0.73
Manufacture of Textile	0.329	-2.37	-0.75	0.323	-0.59	-1.33
Manufacture of Textile Wearing Apparel, Footwear, Caps, Leather, Fur, Feather(Down) and Its products	0.155	-0.82	-0.24	0.351	-0.37	-0.81
Processing of Timbers	0.070	-1.48	-0.51	0.241	-0.89	-2.04

and Manufacture of Furniture						
Papermaking, Printing and Manufacture of Articles for Culture, Education and Sports Activities	0.510	-2.98	-1.04	1.063	-1.37	-3.03
Processing of Petroleum, Coking, Processing of Nuclear Fuel	0.053	-2.53	-0.86	1.123	-1.52	-3.59
Chemical Industry	0.427	-3.93	-1.34	4.227	-3.66	-8.24
Manufacture of Nonmetallic Mineral Products	2.652	-12.01	-4.28	11.741	-7.90	-17.46
Smelting and Rolling of Metals	0.981	-7.26	-2.59	7.665	-6.39	-14.04
Manufacture of Metal Products	0.081	-2.47	-0.88	0.435	-2.03	-4.49
Manufacture of General Purpose and Special Purpose Machinery	0.097	-3.02	-1.13	0.705	2.39	-5.41
Manufacture of Transport Equipment	0.044	-1.99	-0.73	0.251	-1.34	-3.07
Manufacture of Electrical Machinery and Equipment	0.028	-1.77	-0.67	0.212	-2.42	-5.31
Manufacture of Communication Equipment, Computer and Other Electronic Equipment	0.018	-0.72	-0.23	0.124	-0.65	-1.42
Manufacture of Measuring Instrument and Machinery for Cultural Activity & Office Work	0.010	-0.86	-0.28	0.185	-0.93	-2.05
Manufacture of Artwork, Other Manufacture	0.071	-1.21	-0.43	0.783	-1.08	-2.49
Scrap and Waste	0.034	-1.66	-0.62	0.541	-2.02	-4.41
Production and Supply of Electric Power and Heat Power	4.656	-12.18	-4.48	10.469	-7.67	-16.77

Production and Distribution of Gas	0.054	-6.64	-2.93	0.118	-0.45	-1.06
Production and Distribution of Water	0.039	-4.04	-1.35	0.153	-1.42	-3.00
Construction	0.074	-3.41	-1.26	0.424	-2.04	-4.62
Traffic, Transport and Storage	0.911	-2.93	-1.01	3.211	-1.43	-3.33
Post	0.427	-1.64	-0.54	0.917	-0.49	-1.13
Information Transmission, Computer Services and Software	0.003	-1.20	-0.46	0.043	-0.94	-2.11
Wholesale and Retail Trades	0.006	-1.52	-0.55	0.024	-0.90	-2.04
Hotels and Catering Services	0.140	-1.60	-0.57	1.466	-1.03	-2.27
Financial Intermediation	0.013	-1.47	-0.56	0.142	-0.95	-2.08
Real Estate	0.009	-0.71	-0.34	0.137	-0.49	-1.01
Leasing and Business Services	0.074	-1.19	-0.40	0.870	-1.01	-2.35
Research and Experimental Development	0.040	-1.16	-0.39	0.168	-0.59	-1.37
Comprehensive Technical Services	0.052	-1.42	-0.54	0.151	-0.76	-1.78
Management of Water Conservancy, Environment and Public Facilities	0.031	-0.80	-0.30	0.036	-0.13	-0.26
Services to Households and Other Services	0.076	-1.31	-0.52	0.001	-0.53	-1.18
Education	0.014	0.37	0.11	0.177	0.17	0.40
Health，Social Security and Social Welfare	0.049	-0.66	-0.24	0.137	-0.36	-0.83
Culture, Sports and Entertainment	0.025	-0.69	-0.21	0.219	-0.36	-0.82
Public Management and Social Organization	0.122	0.43	0.15	0.406	0.26	0.55

Data source：SICGE-R-CO2 simulation

5. Conclusions and Policy Proposals

The SICGE-R-CO2 interregional model is used in this paper to measure abatement cost and the economic influence of linking the Guangdong-Hubei carbon market. The following conclusions can be drawn from this inter-regional modeling research.

First, a Guangdong-Hubei linked carbon market would dramatically reduce the cost of overall regional emissions reduction. The more participants in carbon trading, the lower the emission abatement cost would be. Therefore, China should actively promote regional carbon market and list these as a key emissions reduction approach during the 12th Five-Year Plan.

Second, Guangdong and Hubei should focus more on key industrial sectors and employ appropriate but different long-term and short-term energy efficiency and emission reductions. Since emissions of the two provinces are highly concentrated in certain industries, reducing emissions in these emission intensive industries should be considered a top policy priority by government. In the short term, a major regulatory measure should be to place limitations on the capacity of emission intensive industries, and the substitution of emissions intense energy through the rapid expansion of non-fossil fuel energy sources should play a supplementary role. In the long run, a pricing mechanism for energy products should be allowed full play to structure the energy mix. Meanwhile, the two abatement mechanisms should be effectively connected.

Third, carbon trading will have quite different impacts on the trading parties. As buyer of emission rights, Guangdong will enjoy lower reduction costs in a trading scenario, while the abatement costs of Hubei will increase. Due to uneven regional development in China, emission abatement costs for enterprises in different regions differ. Therefore, we recommend project cooperation. Enterprises with advanced technologies and equipment and abundant capital in regions of high emissions reduction cost can invest in less developed areas where costs are low, which will ensure both economic development and emission reduction.

Fourth, carbon markets are beneficial to the industrial restructuring process. Energy intensive and emission intensive industries are severely affected, but the services or tertiary sector is largely unaffected. This will help adjust and optimize regional industrial structures, and transform China’s development pattern.

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Part 3: Modelling emissions trading schemes: Australia's experience and China's studies

(3) Direct emissions entitlements and indirect emissions entitlements: Recommendations to the pilot regions' carbon markets in China

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Summary

In the process of designing China's pilot regional carbon markets, an urgent task was to develop a mechanism that covers both direct emissions entitlement or rights (DEE, covering emissions generated from direct combustion of fossil fuel energy such as thermal power stations) and indirect emissions entitlement (IEE, covering emissions generated indirectly by electricity consumption) into the pilot carbon markets. In order to ensure that emission abatement incentives generated by carbon markets that are conducted by the demand side of the electricity market, a carbon market should not only cover both DEE and IEE, but also establish a trading system that allows trading in both. This research paper discusses this particular design, explains the principles underlying the designing process, and provides concrete recommendations to implement the scheme. Moreover, the paper also recommends complementary (regulatory) measures to reconcile the electricity and its related sectors, as these also hold the key to the success of integrated pilot carbon markets.

Taking into account China's current fixed electricity tariff regulating mechanism, especially the fact that electricity tariff adjustments are relatively insulated from the impact of carbon prices, including both direct and indirect emissions in pilot carbon trading markets and allocating IEE on the basis of indirect emissions generated from electricity usage, is compatible with the country's and especially pilot cities' circumstances (moreover, Beijing city is planning to introduce such a system covering both IEE and DEE in 2013, and other pilot cities are considering to follow this model). At the same time, this provided a better solution about how to establish and manage indirect emission entitlements. It is recommended that IEE be enacted on the basis of indirect emissions generated from electricity usage or consumption (in which large commercial, residential and public buildings, and transport, play an important role), in which carbon costs of indirect emissions can be passed downstream to end users.

Introduction

China's 12th Five Year Plan (12th FYP) Outline clearly states the intention of gradually establishing carbon emissions trading markets (carbon markets, for short). By now, two provinces and five cities[39] have initiated their respective regional pilot schemes, aiming to accumulate knowledge and experience for establishing a nation-wide carbon market from 2015-2016.

In March 2012, Beijing, one the pilot regions, announced a plan for carbon emissions entitlement trading. The plan systematically elucidates the underlying considerations of the region's emissions trading scheme. In the scheme, the carbon market will cover three types of entitlements, namely direct emissions entitlement (DEE), indirect emissions entitlement (IEE) and a national verified abatemkent volume. DEE covers the carbon dioxide emissions generated from direct combustion of fossil fuel energy, including the emissions generated by thermal power plants; IEE on the other hand covers the carbon dioxide generated indirectly by electricity consumption.

Internationally, it is unconventional in most carbon markets to cover DEE and IEE simultaneously. The European Union Emissions Trading Scheme (EU-ETS), for example, primarily recognizes emissions from the production side, *i.e.* it mainly covers DEE. Nonetheless, it is not just Beijing's carbon market that covers DEE and IEE simultaneously; other pilot regions such as Shenzhen are also considering including both DEE and IEE in their carbon markets.

This article supports the decision to cover both DEE and IEE in China's pilot carbon markets. Despite being unconventional, it accords with China's current circumstances. This article discusses why it supports this particular design, explains the principles underlying the designing process and provides concrete recommendations to implement the scheme. Moreover, this article also recommends complementary measures to reconcile the electricity and its related sectors, which hold the key to the success of the carbon markets.

2. A carbon market should cover DEE and IEE simultaneously

[39] Two provinces: Guangdong and Hubei; five cities: Beijing, Tianjin, Shanghai, Chongqing and Shenzhen.

(i) Pilot regions should cover DEE and IEE simultaneously to ensure the effectiveness of the carbon markets

A carbon market is part of the China's carbon emission abatement polices. It shoulders the responsibility of abatement, and at the same time it uses market mechanism to optimize resources allocation, as well as facilitates the adjustment of the economic structure. Therefore the effect of carbon market should not only be felt at the point of emissions, but should also be radiated to various other points of economic development.

In a relatively well functioning market economy, when a carbon market covers the direct emission sources, it would be able to pass the cost of carbon emissions downstream, thus providing signals for both the upstream and the downstream to abate emissions. Again, taking the example of the EU-ETS, its primary emissions entitlements are DEE, it covers the stationary emission sources with annual emissions of 250,000 tonnes of CO2-equivalent (CO2e) and above, these sources include the industrial plants of chemicals, cement, steel and most importantly, thermal-powered electricity. Since the EU electricity tariff is determined by the market, power plants could increase the tariff and pass part of the carbon price on to the downstream, dampening enterprises' and residences' electricity demand.

However in China, if carbon markets only cover DEE, it will be difficult for them to achieve the level of cost pass-through as the EU is able to do. Under the current electricity fixed tariff regulations in China, power plants can hardly pass through their incremental cost by increasing their selling prices, this prevents the abatement signals from being channeled to the end users of electricity. Therefore the pilot regions should also include IEE in their carbon markets to enhance the effectiveness of abatement. Including IEE is similar to a market-determined tariff scheme, in which both power generated within the region and purchased from outside the region are included in the carbon market; the mechanism and impact of including IEE is similar to the mechanism and impact of the EU-ETS model.

(ii) Including IEE in pilot carbon markets helps to avoid inter-province carbon leakage

In most pilot carbon market regions, large shares of total energy consumption are electricity consumption, and large shares of electricity consumed are purchased from outside those regions, see Table 1. If carbon markets only cover DEE, it could overtime reduce power generation within the pilot regions and increase these regions' electricity out-sourcing. This will increase other provinces' mitigation pressure, and lead to inter-provinces carbon leakage. This problem can only be avoided by including IEE into the carbon markets, and placing an equal amount of carbon price on all electricity consumption.

Table 1 electricity consumption as percentages of total energy consumption in pilot regions* (%)

		Guangdong	Hubei	Beijing	Tianjin	Shanghai	Chongqing
Total energy consumption[a)]	10,000 tonnes of sce.	26908.0	15137.6	6954.0	6818.1	11201.1	7855.5
Total electricity consumption[b)]	100 million Kwh	4060.1	1417.8	83.9	675.4	1295.9	625.0
Share of electricity consumption in total energy consumption	Calorific value calc'n**	18.5	11.5	14.7	12.2	14.2	9.8
	Coal-eqv. Calc'n***	48.3	30.0	38.2	31.7	37.0	25.5
Electricity purchased from outside the regions as a share of total electricity consumption		21.1	18.5	68.1	16.3	30.8	34.7

Sources: a) China Statistical Yearbook 2011; b) Energy balance tables of respective regions; c) China Energy Statistical Yearbook.

Notes: * no data for Shenzhen; ** 0.1229kgce/kwh; *** 0.32kgce/kwh.

(iii) Pilot regions need to include DEE and IEE simultaneously in order to achieve the energy intensity reduction targets

In the 12th FYP, the provincial and pilot city regions' carbon intensity reduction targets are linked with their respective energy intensity reduction targets. Correspondingly, the regions' carbon abatement efforts should be aligned with their respective energy conservation targets. As it is shown in Table 1, the pilot regions all have large shares of direct fossil fuel consumption and electricity consumption. From the above analysis, covering DEE alone cannot achieve electricity conservation targets, whereas covering IEE alone cannot constrain direct fossil fuel consumption by market mechanism. Therefore a carbon market must cover both DEE and IEE simultaneously.

3. How to include both DEE and IEE into carbon markets

(i) A carbon market should simultaneously cover DEE and IEE and allow trade between the two

First, under the current fixed electricity tariff regulations, when power generators enter a carbon market, they can hardly pass the incremental cost downstream; hence covering both DEE and IEE will not charge the downstream twice. Second, allowing DEE and IEE to be mutually tradable could let the market form a uniform carbon price. This could effectively avoid market distortion, thus maximising the effectiveness of carbon markets, fully exploiting abatement opportunities, and thereby minimises the cost of achieving the designated goals.

(ii) While setting the IEE, one should consider the impact of indirect emissions on the downstream economy

(a) Calculating IEE

In order to include both DEE and IEE into the same carbon market, a key step is to calculate the IEE. This article proposes that the calculation of IEE should be based on a) the amount of indirect emissions generated from electricity usage, and b) the economic impact on the economy of passing the carbon price downstream. This leads to the following equation:

$$IEE = IE * S \qquad (1)$$

According to Equation (1): 1 unit of IEE equals to 1 unit of indirect emissions (IE) multiplies a proportion S, which specifies the proportion of total carbon cost that is allowed to be passed down to the downstream economy. S is a policy variable controlled by the government, it reflects the extent to which electricity users would bear the carbon price. The government determines the level of electricity users' abatement effort by choosing S.

(b) Estimating S

This article proposes an economic analytical framework to estimate S. In doing so we make two assumptions: first, all the power generation enterprises are covered by the carbon market; and second, the electricity tariff is perfectly market-oriented. Under these assumptions, we consider the proportion of additional carbon price that would be passed on to the downstream electricity users.

Figure 1: Electricity-generating enterprises entering the carbon market

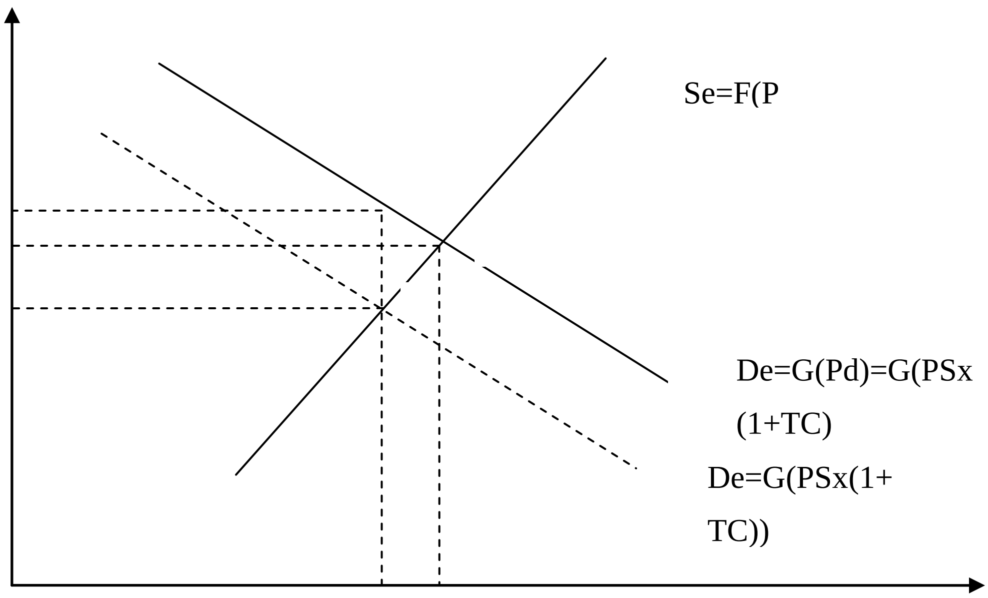

Figure 1 illustrates the changes to the electricity market equilibrium after the electricity-generating enterprises enter the carbon market. The horizontal axis represents electricity consumption or demand, the vertical axis represents electricity price. The carbon price is the difference between the electricity suppliers' price and electricity purchasers' price. To make it easier for presentation, we denote the carbon price as the electricity suppliers' price parameterized by a ratio TC.

Before the electricity-generating enterprises enters the carbon market, the equilibrium of the electricity market is at Point A, the equilibrium electricity consumption is at E, and assumes suppliers' price equals purchasers' price at P. The price of carbon at this point is 0, i.e. $TC = 0$. After the electricity-generating enterprises enters the carbon market, TC increases from 0 to Pc. Then at the new market equilibrium, electricity demand falls from E to E', suppliers' price falls from P to P', and purchasers' price increases from P to P'', the difference between the two prices is ($P' \times Pc$).

After the electricity-generating enterprises enters the carbon market, the total additional cost of carbon is ($E' \times (P'' - P')$), which is equivalent to ($E' \times (P' \times Pc)$). Out of the total additional cost, the generators should bear ($E' \times (P - P')$) and the purchasers should bear ($E' \times (P'' - P)$). Hence under the underlying assumptions, the total additional cost of carbon must be divided between the generators and the purchasers, and the ratio between the two costs should be $(P - P') / (P'' - P)$.

This ratio can be estimated by the following partial equilibrium analytical framework:

$$demand_e = \varepsilon \times pd_e \quad (2)$$

$$\sup ply_e = \varphi \times ps_e \quad (3)$$

$$pd_e = ps_e + ptc \quad (4)$$

From Equation (2), the change in electricity demand $demond_e$[40] is determined by the purchasers' price change pd_e, where ε denotes purchasers' price elasticity of demand (PED). It is a negative number, as demand decreases when purchasers' price increases. From Equation (3), the change in suppliers' supply $supply_e$ is mainly determined by the changes in the suppliers' price ps_e, where φ denotes suppliers' price elasticity of supply (PES). It is a positive number. Equation (4) represents the relationship between the changes in suppliers' price and purchasers' price, the difference between the two is the carbon price.

From Equations (2)-(4), and given market clearance:

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40 In the formula, demand and purchasers' price are all represented as percentage changes, where $demand_e = \frac{\Delta DEMAND_e}{DEMAND_e} * 100$, in which the level variables are written in upper case and the percentage change variables are written in lower case. Equations (3)-(5) are similar.

$$\frac{ps_e}{ptc} = \frac{\varepsilon}{\varphi - \varepsilon} \qquad (5)$$

Equation (5) represents the share of the total additional carbon cost that should be borne by the generators. This share is determined by the relationship between PED ε and PES φ.

If the demand side is more sensitive to price change, i.e. the absolute value of ε is larger than φ, then more than half of the carbon cost will be borne by the relatively less price-sensitive generators, and the remaining less than 50 per cent will be passed on to the downstream purchasers. In this case the S in Equation (1) in theory will be less than 0.5; and *vice versa*.

c) Illustrating by an example

It is assumed that the market is fully competitive both on the supply side and on the demand side. Under this assumption, the absolute values of ε and φ are equal. Then in theory S should have the value of 0.5. Suppose in a region the total indirect emission is 1000 tonnes, thus by Equation (1) IEE should be 500 tonnes.

Hence, when DEE and IEE are allowed to be traded in a single carbon market, the price of DEE and IEE should be the same. Since 1 unit of DEE corresponds to 1 unit of direct emission, the price of 1 unit of direct emission will correspond to the price of 2 units of indirect emission.

(iii) When the additional carbon cost becomes too high as local electricity-generating enterprises enter the carbon market, they should be supported.

Holding the electricity price constant, considering production and consumption separately is the necessary condition for including both DEE and IEE into a carbon market. However for local generators, they cannot pass any of the additional cost on to the downstream. Based on the preceding analysis, under the ideal situation, the optimal resources allocating result is to partially increase electricity price. This will shift part (such as 50 per cent) of the additional carbon cost to the downstream and leave the remaining part (the remaining 50 per cent) to be absorbed by the generator themselves. Therefore under the current electricity tariff regulations, when the tariff is not allowed to adjust, local generators should be compensated accordingly.

Policy recommendations

(i) Covering DEE and IEE simultaneously induces the effectiveness of the pilot regions' carbon markets. We recommend to the National Development Reform Commission (NDRC) that they should urge the regional pilot markets to include IEE into their carbon markets, and make sure they are tradable with DEE.

(ii) In order to ensure the coexistence of DEE and IEE and allowing trade between the two, under the current fixed electricity tariff regulations, electricity tariff would insulate the impact of the carbon price. In parallel, local electricity generators should be rightly compensated.

(iii) It is necessary as well as it is feasible to include DEE and IEE simultaneously into a carbon market. However in application, special attentions should be paid to industries and the impact on enterprises' competitiveness. We recommend establishing industry competitiveness evaluation mechanisms in the pilot regions, to monitor and analyze the competitiveness of important industries and enterprises. This will become the foundation for future carbon market adjustments.

(iv) Covering DEE and IEE simultaneously is the necessary choice for China under the current situation, in which there lacks a uniform nation-wide carbon market and where the electricity market reform program has stagnated. Including the IEE increases the complexity of the application. In a future nation-wide carbon market, the primary emissions entitlement should be DEE alone, and it should let market mechanism to pass carbon cost downstream. It is therefore recommended that electricity market and price reforms should be accelerated in order to establish a nation-wide carbon market in the future.

Part 4: Carbon pricing for China's electricity sector

(1) Analysis of the economic impact of a carbon price under China's regulated electricity pricing system – Application of the SICGE model

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Summary

China has shown a strong willingness to develop a low carbon economy through new economic policies, shifting from the traditional top-down regulatory measures of the previous two five year plans, towards the design and development of cost effective market-based carbon price solutions such as carbon emissions trading or the possible introduction of a carbon tax.

This paper explores the application of an RMB 100/tonne CO2 carbon price ($US 16/tonne) to SIC's China SICGE model, developed with the assistance of Monash University's Centre of Policy Studies. Using five scenarios and complementary policies, the short and long term impact on carbon emission reductions and on the nationwide economy were simulated. When simulating these policy scenarios, the existing market distortions in China were taken into consideration, especially the highly regulated electricity prices. A flexible mechanism was introduced into the SICGE model to make electricity prices exogenous or these prices were kept endogenous, with the aim to compare the economic impact of carbon pricing in three scenarios using different assumptions. In another two scenarios, the impact of different ways to re-distribute the carbon price revenue (from emission permit auctions in an ETS, or from a carbon tax) were simulated.

The following main conclusions were drawn from the research paper's policy scenario simulations:

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(1) Carbon pricing is an effective policy for China to reduce CO2 emission. Even with a fixed or stable electricity price, an RMB 100/tonne carbon price could lead to a CO2 emission reduction of 6.8% relative to the base scenario

(2) Keeping the electricity price stable when introducing a carbon price can be seen as a government subsidy to China's economic system. This would reduce the GDP loss from carbon pricing, but other policies would be needed to promote electricity efficiency and fossil fuel energy saving

3) When comparing the five policy assumption scenarios, and considering reductions in GDP loss while ensuring carbon emission reductions from carbon pricing, the fixed or stable electricity price scenarios are less efficient than those cases which were based on flexible electricity prices. These scenarios assume re-distribution of carbon price revenue in such as way as to promote economic system efficiency, such as reducing production taxes or reducing sales tax of consumption

4) Comparing the results of two simulation scenarios assessing options for the re-distribution of carbon price revenues, in the short-term, reducing sales taxes on consumption is shown as being superior. However, in the long-term, reducing production taxes will result in greater economic gains. It is recommended for policy consideration that the re-distribution of carbon price revenue system adopts an integrated approach to reduce both consumption and production taxes simultaneously

1. Introduction

China has shown a strong willingness to develop a low carbon economy (LCE) in recent years. During the 11th Five-Year period (2005-2010), China's energy intensity (total energy consumption per GDP) decreased 19.2%; at the end of 2009, China central government announced that China would reduce carbon intensity (total CO2 emission per GDP) by 40-45% from 2005 levels by 2020, and in the 12th Five-Year Plan (12th FYP), the reduction of energy intensity and carbon intensity were both identified as the compulsory target, which would be reduced by 16% and 17% respectively. China's CO2 emission abatement plans were not only introduced to cope with international carbon emission reduction pressure, but were also seen as the "key tool" to promote a new economic development and growth pattern and the transformation of China's economic and energy structure. Hence, a low carbon economic development policy direction has been adopted and popularised throughout China, which means China must simultaneously deal with sustainable development, clean energy, as well as environmental protection. Since the introduction of China's large and deep CO2 emission reduction program in the 11^{th} FYP, command-and-control regulatory policies have prevailed, especially in the energy sector. These comprised widespread nationwide programs such as "the closure of small and inefficient factories and thermal power plants", "large installation substitute small", "promoting energy efficiency standard", "subsidy on renewable power generation", and so on. These policies usually achieved rapid results and will probably play a continuing role in the following years. However, measured in economic terms, these programs were very expensive and impacted greatly on regional and local economies, were usually less cost-effective, and less comprehensive than market-based instruments (Baumol and Oates, 1988). Some economic instruments existed to manage the demand of energy efficiency and climate change, but these are discrete, and sometimes were of ambiguous transparency, such as China's export tax on energy-intensive (EI) products (Wang and Voituriez (2010)).

The cost-effectiveness and comprehensiveness of a climate change policy have long been identified as a priority and preferred clean energy direction by the Chinese government. The December 2007 Communist Party's Central Committee Conference on economic issues demanded a "speeding up in the implementation of fiscal, tax and financial policies to save energy and reduce CO2 emissions". More recently, the "*Central Communist Party's Suggestion on the Making of the 12^{th} Five Year Plan* (2011-2015)"[42] proclaimed that China would implement a new environmental taxation scheme and will gradually establish an Emission Trading System (ETS) for curbing CO2 emissions. China would launch pilot emissions trading schemes in seven provinces/cities (Beijing, Chongqing, Shanghai, Tianjin, Shenzhen, Hubei and Guangdong) by 2013 and set up a nationwide trading platform by 2015-2016[43].

Regardless of the choice between the levying of a fixed price or carbon tax in China, or introducing an ETS for China, carbon emissions covering production and consumption would be subject to pricing, so as to expand the influence of a carbon cost to all economic activities. However, since there exist fixed price regulations in

42 Implemented on October 18, 2010.

43 "China to expand carbon trade after 3-5 years", China Daily, 12/03/2011, http://www.chinadaily.com.cn/china/2011-12/03/content_14208137.htm

electricity and gas and petroleum products, and there are other market distortions in China's energy sector (making China's situation very different from the competitive markets of developed countries), the policy direction and final economic impact of policy measures will be different from an economy where there are no market distortions. To support China's policy making in a period of reform and transition, it is necessary to consider how to model non-market mechanisms in order to simulate the impact of a carbon tax or ETS in China using model such as a CGE model.

There exist some recent studies which are focused on the impact of carbon pricing in China, and which aim to assess the direct short-term impact on industrial competitiveness, based on Input-Output tables and sectoral energy consumption data (Wang et al., 2011). Most of these approaches are undertaken through CGE modelling, and aim to assess the short-term or long-term impact of carbon pricing in China (for example, Jiang et al., 2009; Su et al., 2009; Wang et al., 2009, Liang et al., 2007). Usually three indispensable aspects were taken into account to support the public policy decision: the impacts on the economy, on households, and the effect on CO2 emissions reduction. However, there was little consideration about the market distortions in China mentioned above.

For this paper, a revised and updated CGE model for China was used by the State Information Center to estimate the short-term and long-term impact of carbon pricing, and in particular emphasised the following three aspects: 1) impact on industrial competitiveness, considering that industrial sectors (including China's power supply sectors) account for a very important share of both the Chinese economy and CO2 emissions; 2) comparison between the results when considering the regulated or fixed electricity price with the results without such consideration; 3) find ways to return back the revenue from carbon pricing to the economic system in an effective way. The remaining content of the research paper is organised as follows: Part Two presents the methodology; Part Three provides the data; and Part Four examines the results, prior to providing a conclusion.

2. Model

(i) General presentation

Jointly developed by the State Information Center (SIC) of China and Monash University of Australia (Centre of Policy Studies), the State Information Center CGE (SICGE) model is used by the Chinese government as an auxiliary tool for the development of public economic policies. Based originally on China's 2002 Input-Output table, the SICGE model includes 137 sectors, 3 categories of production factors (labor, capital and land), 5 labour types, 8 kinds of margins as well as parameters of technology change, consumption preference and market distortion, etc (Zhang and Li, 2010). Substitution between energy and capital, and substitution between coal product and oil/gas products were introduced in the SIC-GE model (Zhang,C.L., ed al. 2011). The core and dynamic modules of SICGE are based respectively on the ORANI model (Dixon et al., 1982) and the Monash model (Dixon, P.B and Rimmer, 2002).

(ii) Model on regulated electricity prices

Most of China's electricity generation enterprises are state-owned. When the electricity price controlled by the government is lower than the production cost, the government would compensate the gap through fiscal transfers. This is the case of "soft budget constraint" (Qian and Roland. 1996), and the compensation of the gap can be seen as an economy wide subsidy from government, through the lowering of the price of electricity. In terms of the CGE model, Vincent, D.P., etc (1979) had used a phantom tax variable to model the gap. This approach has been adopted in the SIC-GE model, so that electricity prices can be made exogenous, and the phantom tax is made variable endogenous. As a result, the electricity price could be shocked to simulate the case for regulated electricity price.

(iii) Model on labour market segmentation

Labour market segmentation remains pervasive in China. There exists a certain degree of non-competitiveness among different labour markets, and labour mobility is relatively low (Hertel and Zhai, 2006; Knight and Li, 2005; Knight and Yueh, 2004), despite the fact that the factors hindering labour mobility among regions and sectors are diminishing. In general, unskilled labour forces with a relatively high degree of mobility and competitiveness are dominant in labour intensive sectors (for example, textiles and toys), while skilled and well-trained labour forces with low unemployment rates and high salaries still account for only a minor share.

Based on such actual segmentations, the SICGE model divides the total labour force into five categories: farmers, employees of township enterprises, rural-urban migrant workers (nongmingong), the urban unskilled labour force and the urban skilled labour force. Each labour force is classified into a single category at a time. Each category cannot always be employed by all industries. For instance, farmers can only be employed by the agricultures sector and cannot be employed by the industry and services sectors. However, a mobility mechanism is built in SICGE: first, labours can flow among different sectors given in a labour type category; Second, among different categories such as farmers, employees of township enterprises and migrant labour forces, the flow is determined by the gap between demand and supply of these three categories and the preferences of mobility among them; Third, labour forces comprising farmers, employees of township enterprises and rural-urban migrant workers cannot freely flow into urban unskilled labour forces and urban skilled labour force categories. This is due to the skill difference and the rural-urban “citizenship” (“hukou” or residential registration) mechanism which limits the permanent living period of rural labourers in urban China. Importantly, such labour module settings enable a detailed analysis on the impact of an ECT on labour markets, given that a significant number of unskilled labour forces, particularly migrant workers, are employed in China’s export-oriented industries. If an ECT affects export-oriented industries it could generate an oversupply of unskilled labour, which may not be easily absorbed by other sectors due to labour segmentation.

(iv) Recursive dynamic

The dynamic impact analysis is obtained in the recursive form with the SICGE model. Herein, for each sector, the capital stocks at the beginning of year t+1 are equal to the capital stocks at the end of year t, and are the sum of the capital stocks at the beginning of year t and the total investment in year t minus the depreciations in year t. Based on such setting, the policy shock in year t will have no impact on the capital stocks at the beginning of year t, but will change the industrial expected rate of return, which in turn could affect the industrial investment in year t and the capital stocks at the beginning of year t+1.

During the calculation of the dynamic impact of the policy shock in the SICGE model, the special sticky mechanism is used for the change of labor and real wage relative to the value in base case (including historical and forecasting value), following the work of P.B. Dixon and M.T. Rimmer(2002). In most CGE applications, it is assumed that employment is fixed and the labor market is reached through a change in real wage. This can be seen as the long-run mechanism. For other applications, it is assumed that wages are unaffected by the policy shock. This entails involuntary unemployment, which can be seen as a short-run mechanism. Here a compromised way has been adopted, with wages sticky in the short run and flexible in the long run.

(v) Options for simulating carbon cost using the SIC-GE model

There are several ways to introduce carbon cost into the SIC-GE model. Firstly, the unit carbon price is converted to ad valorem tax rates of fossil fuels at the base year, and then these rates are kept constant for the following simulation years. This approach keeps the carbon cost at a constant price (and an increasing nominal price across year taken into account the inflation effects).

Concretely, for each industry, the additional carbon cost is only added on the primary energy intermediate inputs and the imported secondary fossil fuel intermediate inputs of each sector. Given that the SIC-GE's input-output (IO) table only includes two energy types ("coal and products"; and "oil and natural gas and products"), the following system is adopted to account for a sector's direct fossil fuels consumption in a more detailed manner. Equations 1-4 set the framework for converting unique carbon cost into ad valorem taxes imposed on primary energy. The index "i" denotes the "ith" sector, the index "j" denotes the "jth" fossil fuel type included in the IO table of the SIC-GE model, the index "m" denotes the "mth" fossil fuel type provided by the Energy Statistical Yearbook of China (ESY) and the index "H" denotes the household sector. Here, i = 1-44.[44] Respectively,

t_i^j = ad valorem tax rate of the jth energy for the ith sector

t_H^j = ad valorem tax rate of the jth energy for the household sector

t = unique carbon cost

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[44] The division of the sector into 44 industry sectors is due to the fact that only detailed energy consumption data of the mth type of energy are available at this sectoral level. Details of the 44 sector divisions can be consulted at the NSB's China Energy Statistical Yearbook.

DC_{ij} = direct CO2 emissions due to the consumption of the jth energy of sector i

DC_{ij} = CO2 emissions generated by the jth type of energy of the ith sector

DC_{Hj} = CO2 emissions generated by the jth type of energy of the household sector

V_{ij}^{E} = value of the intermediary input of the jth energy into the ith sector (in monetary form)

V_{Hj}^{E} = value of household consumption of the jth energy (Both V_{Hj}^{E} and V_{ij}^{E} could be obtained from the non-competitive IO table of China)

E_{xm} = mth energy consumption of the xth sector (x = i and H)

C_m = mth energy carbon content (same as C_j of equation 1)

rb_m = mth energy combustion rate (same as rb_j of equation 1)

For equations 3-4, it is given that m= coal when j=coal; and m= crude oil, natural gas when j= oil and natural gas. Such arrangement is due to the fact that the SIC-GE model uses two types of primary fossil fuels (represented by "j"). The direct CO2 emissions are calculated from crude oil and natural gas separately and summed up for "oil and natural gas" which is given in one category of primary fossil fuels in SIC-GE.

$$t_i^j = t * DC_{ij}/V_{ij}^{E} \quad (1)$$

$$t_H^j = t * DC_{Hj}/V_{Hj}^{E} \quad (2)$$

$$DC_{ij} = \sum_m E_{im} C_m \, rb_m \quad (3)$$

$$DC_{Hj} = \sum_m E_{Hm} C_m \, rb_m \quad (4)$$

When converting the carbon cost into an ad valorem tax rates on imported petroleum products, an average ad valorem tax rate was applied for petroleum products (t^{petrol} here) across industries due to data limitations (equation 5). Respectively,

t^{petrol} = average ad valorem carbon tax for imported secondary energy

DC_k^{im} = CO2 emissions generated by the kth imported secondary energy, in this instance gasoline, kerosene, diesel oil and fuel oil, calculated using the same value of carbon contents and combustion rate (respectively C and rb in previous equations)

$V_{i,petrol}^{im}$ = imported amount (in monetary terms) of petrol refinery products in sector i ($V_{i,petrol}^{im}$ can also be obtained from the non-competitive IO table of China)

$$t^{petrol} = t \times \left(\sum_k DC_k^{im}\right) / \left(\sum_i V_{i,petrol}^{im}\right) \quad (5)$$

(vi) Integration of a carbon price into the SIC-GE model

It is assumed that the increase of ad valorem tax rates from the imposition of a carbon price is exogenous. The shock can be made directly on the sales tax rates for energy intermediate inputs for all industries and final consumptions. In SIC-GE, the purchaser price of product i involve three parts, producer price, sales tax and margins, as shown in equation (6). Transferring the variables in equation (6) into the percentage change form, shown as lowercase ($t = \frac{\Delta T}{T} * 100$) in equation (7), is in accordance with the equation mechanism in SIC-GE model. A carbon cost can be introduced through shocking of pi in equation (7). It needs to be noted that margin variables mar_i are endogenous, and also will change following the change of fuel cost of margin sector when introducing carbon pricing.

where, for a given ith sector

$P_{pur,I}$ = purchaser price of the product

$P_{base,i}$ = base price (producer price) of the product

Ti = sales tax (such as VAT, consumption tax, etc.)

$Margin_i$ = charge of transport and trading fee

$p_{pur,I}$ = change of the purchaser price

$p_{base,i}$ = change of the base price

p_i = change of Pi=(1+Ti), known as the power in CGE terms

mar_i = change of the margin

S_i^{mar} = share of the margin on the purchaser's price

$$P_{pur,i} = P_{base,i}(1 + T_i)(1 + Margin_i) \qquad (6)$$

$$p_{pur,i} = (1 - S_i^{mar})(p_{base,i} + p_i) + S_i^{mar} * mar_i \quad (7)$$

3. Data and scenarios

(i) Sector classification and economic data

This paper adopts 2007 data and uses 2007 as the base year. However, the most detailed publicly available data of sectoral energy consumption by fossil fuel types provided by China's Energy Statistical Yearbook (ESY) is aggregated at the 44-sector level. For both reasons of simplicity and data availability, the sectors were re-grouped in the SIC-GE model into 44 corresponding sectors. Detailed explanations of the division of sectors, data sources as well as the statistical compatibility of data from different sources is provided in Annex A.

(ii) Sectoral fossil fuel consumption

Fossil fuel consumption per sector in 2007 was obtained based on China's 2008 Energy Statistical Yearbook. The carbon contents and combustion rates of fossil fuels were obtained respectively from the IPCC (2006) and Ou et al. (2009). Annex B lists related data. It must be noted that the CO2 emissions produced by industrial processes are excluded due to data unavailability. This could significantly reduce the impact of the carbon cost on sectors with high process CO2 emissions, for example, the cement sector. Further studies may include such process emissions, particularly, based on the industrial process CO2 emission inventory, which is soon due for completion.

(iii) Scenario settings

The impact of a carbon price of RMB 100/tCO2 (roughly 11-12 euro/tCO2 or $A 16/tCO2) was examined. Comparing to the commonly proposed "safe start rate" of RMB 10/tCO2 in China, this rate may be considered more effective and challenging. The baseline scenario (named S0) is given for the period of 2007 based on Mai (2006). Major macroeconomic variables of 2007 under S0 are given under the growth rate form in table 1. The first column of Table 1 also provides real 2006 data of these variables.

Table 1. Major macroeconomic variables under baseline scenario (%)

	2006 (real term) (RMB 10^8)	2007	2008	2009	2010	2011-2015
GDP growth (1)	222240.0	14.2	9.5	9.2	10.3	9.0
Consumption growth	112631.9	10.6	8.8	10.8	5.5	9.4
Capital formation growth	92954.1	13.9	10.6	28.7	11.4	9.9
Export growth	84615.9	19.9	8.4	-19.4	16.7	8.4
Import growth	67965.8	15.8	7.7	-10	15.6	8.5
CPI growth	-	4.4	5.9	-0.7	2.2	2.9
Employment growth	7.64 (10^8 person)	0.8	0.6	0.6	0.6	0.6

Note: (1) Growth rate is given under constant price of 2007.

Source: SIC-GE.

Five policy scenarios were assessed which can be divided into two groups. Firstly, the revenue of the carbon price is not redistributed specifically and used to ease government deficits. Under this assumption we have three policy scenarios which take account the current electricity market price regulation in China:

S1). Only shock the ad valorem tax rates for each sector and final consumption; it is assumed that total carbon cost could pass through the electricity sector, so that the electricity price will not be regulated, and hence can fluctuate and follow the carbon price.

S2). Shock the ad valorem tax rates like S1, and let the electricity price change by half in S1. This case means only a 50% electricity carbon cost pass through of the electricity sector, so that the electricity price is regulated, and will be partly adjusted to follow the change of carbon pricing, and the gap between electricity price and total production cost will be compensated through government subsidies.

S3). Shock the ad valorem tax rates like S1, and keep the electricity price the same as that in the base scenario. This means no carbon cost pass through in electricity sector, so that the electricity price are also regulated, and prices are kept stable by government whether there are carbon costs or not. The gap between the price and total costs will be totally covered by government subsidies.

In S2 and S3, the government subsidy on the electricity sector can also be known as the subsidy to the whole economic system through the electricity product.

Secondly, the revenue from the carbon price is earmarked. Under this assumption, two scenarios are provided where the carbon costs of the electricity sector are freely passed through under the assumption of governmental authorization:

S4). Shock the ad valorem tax rates, and allow a flexible electricity price as in S1. The revenue from the carbon price would be redistributed to reduce the production tax for enterprises by the same ratio, so to keep the government deficit neutral.
S5). Shock the ad valorem tax rates, and allow a flexible electricity price as in S1. The revenue from the carbon price would be redistributed to reduce the sales tax of consumption commodities by the same ratio, so as to keep the government deficit neutral. For S5, consumption would be stimulated to follow the central objective of the 12th Five Year Plan (2011-2015) which aims to promote a consumption-driven GDP growth.

4. Results

(i) Corresponding ad valorem tax rates on fossil fuels at sectoral level

As mentioned above, the carbon cost is introduced by the shock on the ad valorem tax rates of intermediate inputs and the household consumption of the primary energy product. The results are shown in Table 2. In terms of the carbon price on imported petroleum products, the average ad valorem tax rate of 8.88% can be obtained.

Table 2. Equivalent sectoral level ad valorem tax rates on fossil fuels at RMB 100/tCO2 (%)

Sectors	Coal	Crude Oil and Natural Gas
Agriculture	155.2	0.0
Mining and washing of coal	30.3	0.8
Extraction of petroleum and natural gas	27.1	27.2
Mining and processing of ferrous metal ores	15.8	0.0
Mining and processing of non-ferrous metal ores	13.5	0.0

Mining of other ores	118.3	0.0
Manufacture of foods, beverages and tobacco	57.0	0.1
Manufacture of textile	41.5	0.1
Manufacture of wearing and leather	12.5	0.1
Lumber and furniture	12.4	0.1
Manufacture of paper and paper products	85.8	0.5
Printing, reproduction of recording media	14.5	0.2
Manufacture of articles for culture, education and sport activity	7.5	0.2
Processing of petroleum, coking, processing of nuclear fuel	40.8	7.6
Manufacture of raw chemical materials and chemical products	30.5	6.3
Manufacture of medicines	179.9	0.5
Manufacture of chemical fibers	59.7	0.1
Manufacture of rubber	21.7	0.4
Manufacture of plastics	19.3	0.2
Manufacture of non-metallic mineral products	26.7	0.6
Smelting and pressing of ferrous metals	42.1	0.2
Smelting and pressing of non-ferrous metals	20.8	0.2
Manufacture of metal products	9.5	0.1
Manufacture of machinery	11.0	0.2
Manufacture of transport equipment	47.5	0.4
Manufacture of electrical machinery and equipment	16.8	0.2
Manufacture of communication equipment, computers and other electronic equipment	42.5	0.5
Manufacture of measuring instruments and machinery for cultural activity and office work	5.0	0.1
Other manufacturing	20.2	0.0
Electricity & Heat	71.1	0.5
Gas production and supply	37.5	0.0
Water production and supply	44.0	0.0
Construction	17.7	0.7
Transport & stock	17.9	4.9
Trade, Accommodation, restaurant	86.7	0.4
Other services	8.5	0.5
Household Consumption	97.6	0.9

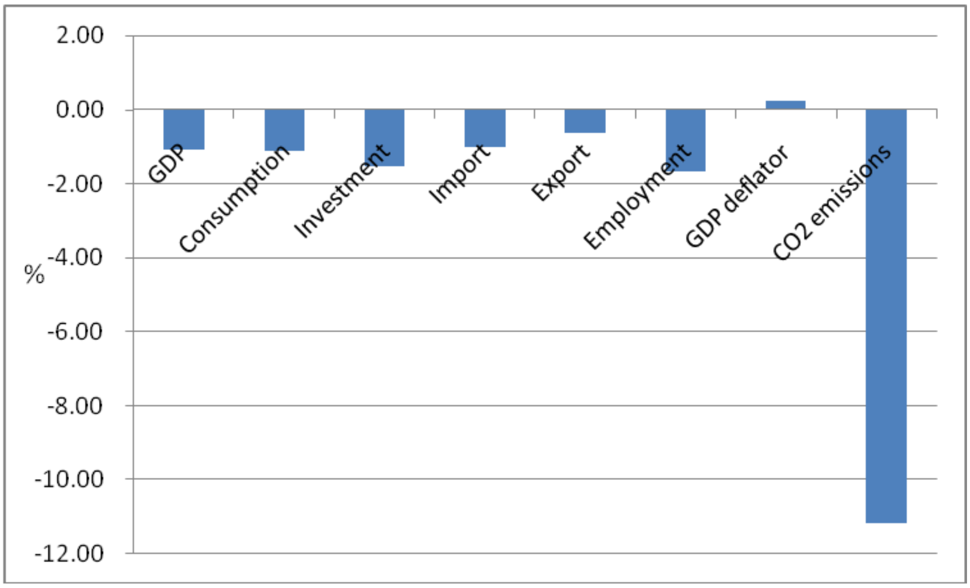
Source: Authors

(ii) Macro economic impact results and a simplified analytical framework

The short-term impact of S1 is sufficiently representative for understanding the fundamentals of the SIC-GE model, and then to make comparisons among scenarios. For clarification, when comparing policy scenarios, the reference scenario is S0 if not specified. The variation of parameters is given in percentage form which indicates the change with regard to the baseline (reference scenario S0) level.

The short-term macro economic impact of a carbon price under S1 are shown in Figure 1, following the short-term assumption that real wages, capital stock and technology parameters are all almost stable. As seen, with a carbon price of RMB 100/tonne CO2, the negative macro economic impact is as follows: relative to the baseline level, the GDP is reduced by 1.1% (leading to a GDP growth of 13.1% comparing to 14.2% of reference scenario). Consumption is decreased by 1.13%. As a result of a decrease of about 3.37% in the real rate of return (ROR), investment is reduced by 1.52%. The introduction of carbon pricing is shown to lead to a domestic price increase about 0.22% relative to the baseline, which leads to a real appreciation of the currency and therefore contributes to a decrease in exports of 0.64%. Imports were reduced by 1.02% mainly due to the weakened domestic demand, but partly compensated by the effect of the real appreciation of currency. Employment decreased 1.66%. To help readers unfamiliar with the CGE model to understand the macro results, a simplified framework is constructed in Annex C, which provides a detailed and comprehensive explanation of the results obtained by the SIC-GE model, based on the Dixon and Rimmer approach (2002).

Figure 1. Macroeconomic impact of the carbon price in 2007 under a carbon price of RMB 100/tCO2 (S1)

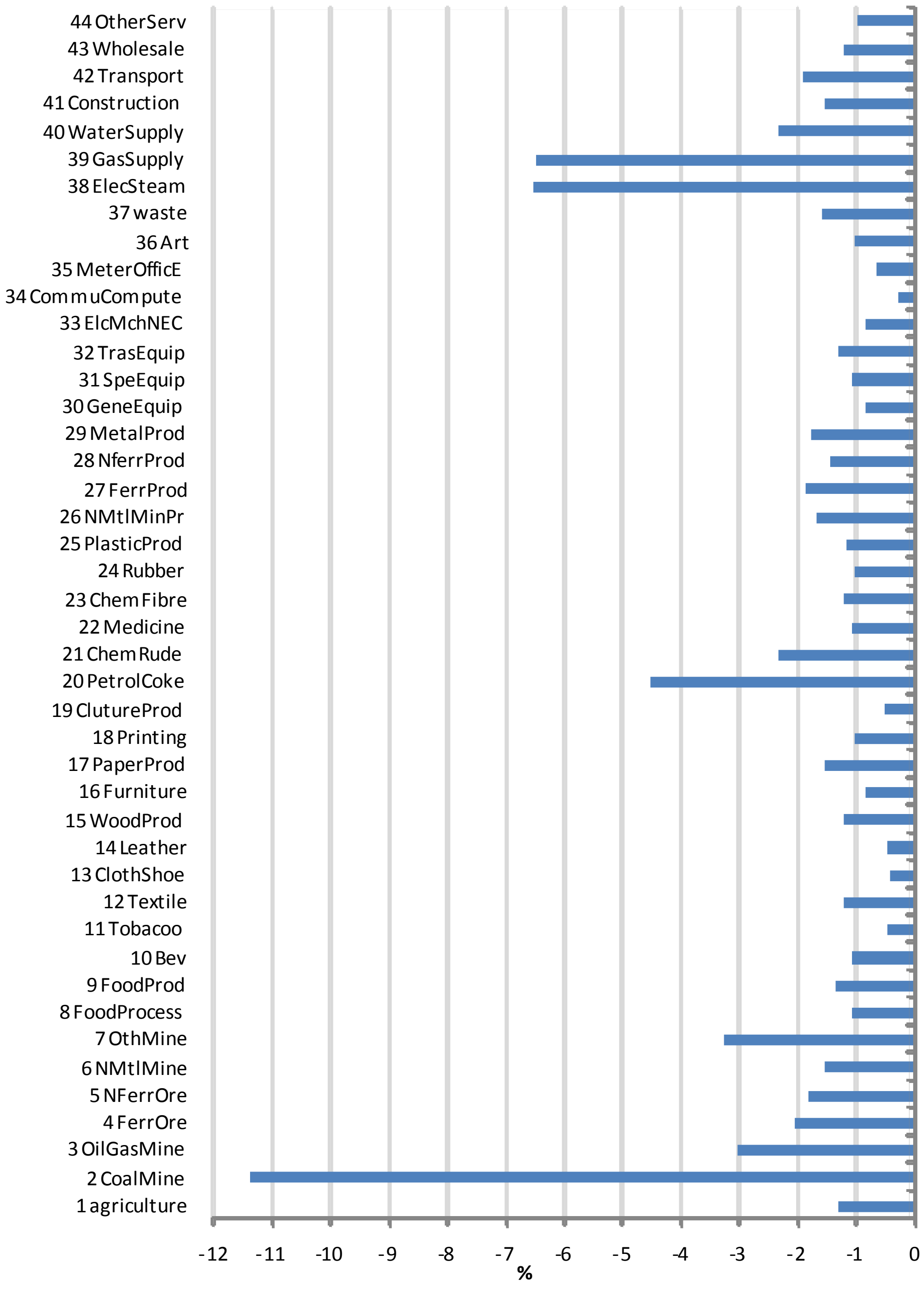


(iii) Impact on industrial output changes

According to Figure 2, the output of all industries decreased under a carbon price of RMB 100/tCO2 under S1. Particularly and not surprisingly, the output of the energy supply sectors is drastically cut. For primary energy, the coal mining (2), crude oil and gas mining(3) reduced relative to the base scenario respectively by 11.4%, 3%; and for imported petroleum product, shown in an aggregated products here, the petroleum coke (20), reduced by 4.6%. There was a big reduction for coal mining products (2), mainly because of the following two reasons: 1) the output of all users decreased. For instance, the main users, electricity power and heating generation (38), coke (shown as the sector 20) and ferrous metal (shown as the sector 27) reduced by -4.6%, -6.6%, -1.87%, respectively, which are all higher than the average reduction, shown by GDP. 2) The substitution effects. In the SIC-GE model, a mechanism allows for the substitution between energy and primary factors, like labor in short-term, and capital in long-term, and the substitution between different energy products. Considering that the direct effect of carbon pricing is increasing the purchasers' price of energy product relative to other inputs, and increasing the price of coal product more than oil and gas, coal production should fall the most.

The secondary energy, as in petroleum and coke (20), electricity power and heating generation (38) and gas supply (39) sectors reduced relative to base scenario respectively by-4.6%, -6.6%, -6.5%, and the output of major energy intensive sectors is reduced by about 2-3%. Also, the output of light industries and labor-intensive sectors is reduced by about 1%.

Figure 2. Industrial output changes in 2007 under a carbon price of RMB 100/tCO2 (S1)



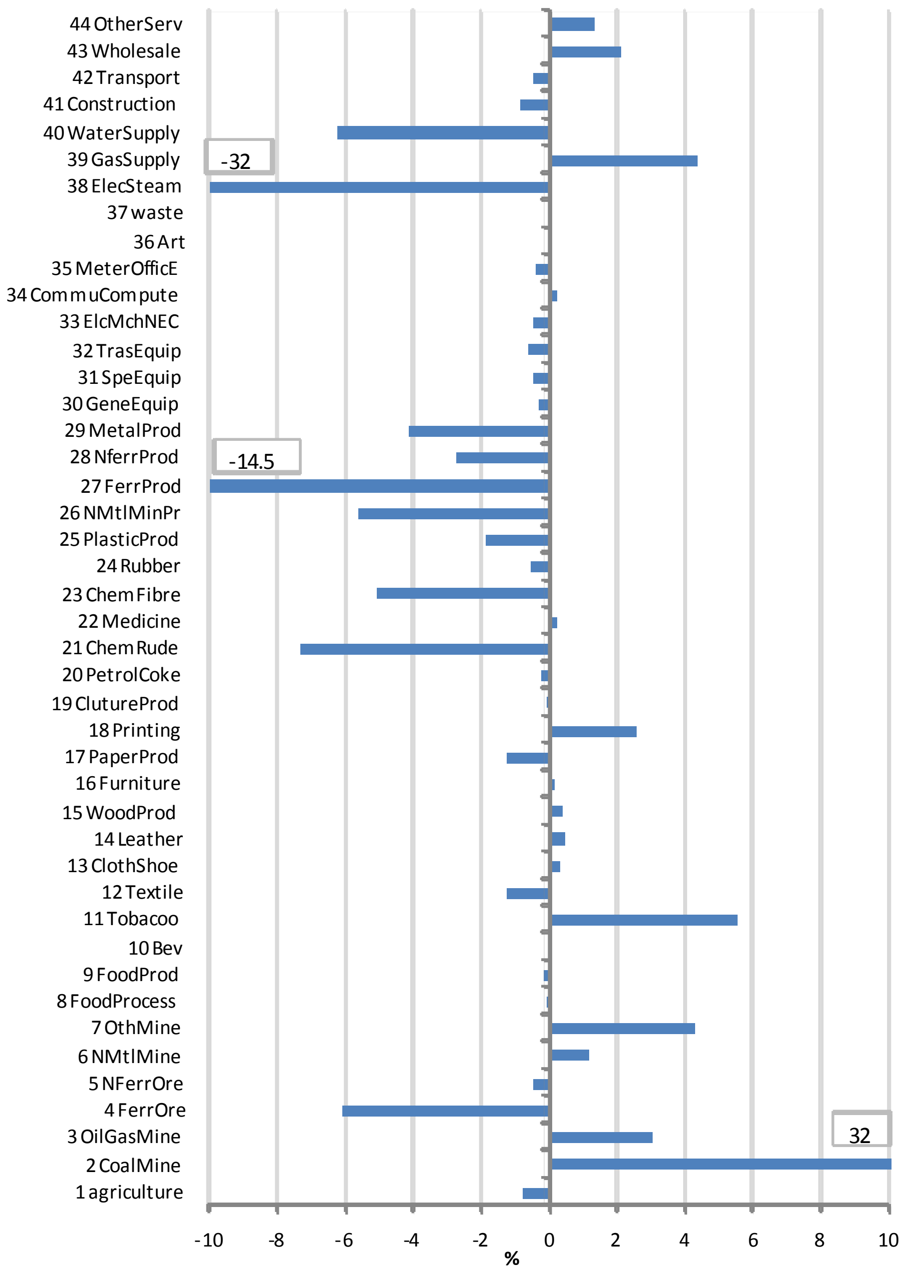
(iv) Export impact analysis

The competitiveness impact, measured in terms of the impact of the carbon cost on industrial exports, varies greatly among sectors. As Figure 3 shows, the export of most energy intensive sectors will decrease (dramatically) under a carbon price of RMB

100/tCO2. For example, the export of ferrous metal will be the most seriously affected sector, with a reduction of up to almost one third of its total export. This corresponds to what Wang et al. (2011) finds on the high sectoral carbon intensity of the ferrous metal sector in China.

On the other hand, exports of certain sectors are actually stimulated under a carbon pricing policy. For example, energy products (such as coal, oil products and natural gas and its products) and some manufacturing products (including tobacco, printing, computers, clothing and some services) show an increase in exports. This can be explained as follows.

Figure 3. Change in industrial exports in 2007 under a carbon price of RMB 100/tCO2 (S1) (%) (Source: SIC-GE model)



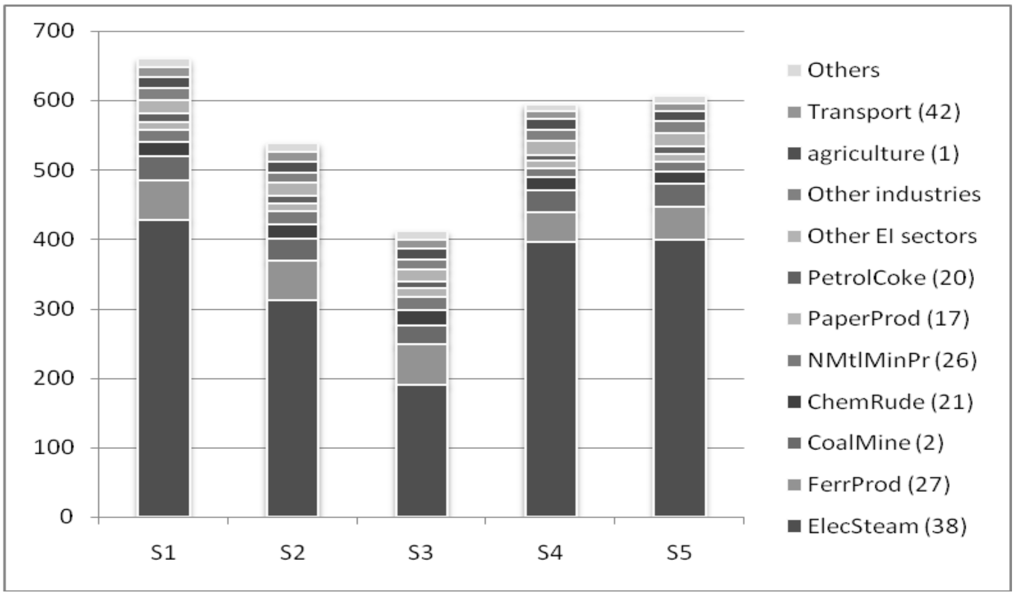
For energy products, carbon pricing would lead to its producer price going down, when its purchase price increases, since a carbon price does not apply to the export of energy product. The export price reduces relative to the base scenario following the producer price, increasing exports. For instance, the producer price of coal is reduced by about 7.9%, but the FOB price of coal is reduced by about 7.1%, which could roughly increase the export of coal about 28% (close to the model results, 32%) relative to the base scenario, Considering the demand, the elasticity parameter is about 4 for coal.

For non-energy product sectors showing an export increase, it is important to study their cost structures. In 2007, for example, in the printing, tobacco and service sectors, their capital cost ratio on total cost was, respectively, 19.1%, 34.1% and 24%, all of which are above the general average value for all sectors (15%). Considering that, in the short-term, the capital rental rate would decline (in 2007, the general reduction of the capital rental rate is -3.2%) because of the reduction in labor demand and fixed capital stock. Then the reduction of capital cost would lead to a reduction of total cost, which could cover the increase of energy cost and lead to a small reduction of producer price of these products, which would then promote their exports a little.

(v) Impact on CO2 emission

The CO2 emission reduction effect is significant under a carbon price of RMB 100/tCO2 under S1. According to the model, the total reduction in CO2 emissions will be 661.46 million tonnes, corresponding to an 11.16% reduction relative to the baseline scenario. A reduction in the domestic consumption of coal and coal products, which decreased by 12.5% relative to the baseline case, provides the major contribution towards total CO2 emission reduction. The electricity and steam supply sector is particularly significant, with a reduction of coal consumption together with other fossil fuels accounting for a CO2 emission reduction of 428 million tonnes of CO2 (see Figure 4). The second greatest contributing factor to the decrease of CO2 emissions is the emission reduction in the (heavy) industrial sectors (such as ferrous metal, chemical products and coke, etc.). While the major absolute reductions of CO2 emissions occurred in the energy-intensive sectors, the highest CO2 emission reduction in percentage terms relative to the baseline scenario was provided by the pharmaceutical sector (-36%). This is principally due to the high equivalent ad valorem carbon price rate that the carbon price will generate (cf. Table 2).

Figure 4. Sector CO2 emissions[45] reduction in 2007 (MtCO2)



Source: SIC-GE based on 2007 real sectoral CO2 emissions, 2008 Energy Statistical Yearbook.

(vi) Comparison among scenarios

Table 3 compares the macroeconomic impacts of an RMB 100/tCO2 carbon price on major economic and climate indicators among various policy scenarios. As shown, S5 can be considered the best option among the various scenarios provided here in terms of short-term impact (yet this will not be a final option, as will be shown below in the long-term impact comparison). The positive GDP growth under S5 is due to the high growth of consumption which compensates the negative GDP growth impact generated by the carbon price. The high consumption growth has also generated a positive employment rate and import growth. Comparing S1, S2 and S3, the zero carbon cost pass-through for electricity sector could reduce the negative macroeconomic impact, but also lead to lower CO2 emissions reduction level due to different levels of electricity output (the output of electricity and heat production sector will reduce respectively 3.45% and 0.35% in S2 and S3, compared with 6.56% in S1).

Table 3. Comparison of different scenario (%)

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45 The CO2 emissions for a sector only involve the CO2 emissions from direct fuel consumption.

	S1	S2	S3	S4	S5
GDP	-1.10	-0.82	-0.56	-0.46	0.22
Consumption	-1.13	-0.84	-0.57	-0.58	1.50
Investment	-1.52	-0.90	-0.26	-0.13	-0.27
Import	-1.02	-0.75	-0.48	-0.18	0.11
Export	-0.64	-0.69	-0.79	-0.48	-0.91
Employment	-1.66	-1.23	-0.80	-0.42	1.07
GDP deflator	0.22	0.31	0.44	0.32	-0.71
CO2 emissions	-11.16	-9.00	-6.75	-9.97	-10.14

Source: SIC-GE.

In the attempt to compare model results of different carbon revenue redistribution modes, only S1, S4 and S5 are adopted for sectoral level comparisons. As Figure 5 shows, the sectoral output of most of the sectors providing consumption goods (such as agriculture, food production, cloth and shoes, etc.) have achieved an increase relative to the reference scenario under S5. This is due to the increasing consumption demand as the result of the reduction of sales tax of the consumption products. Yet, the output of most energy-intensive sectors (ferrous metal, basic chemical, etc.) still decreased.

In terms of export change comparison among the same three scenarios (Figure 6), most of the sectors have followed the same trends. Yet the export of major consumption product sectors (textiles and shoes, for example) decreased in S5 different to S1 and S4, a result of the effect of rising domestic consumption, which has driven a higher export price on such products.

Figure 4 shows that among five policy scenarios, most of the CO2 emissions can be reduced in the electricity and heat production sector.

Figure 5. Industrial output change comparison: S1, S4, S5 (%)

(Source: SIC-GE model)

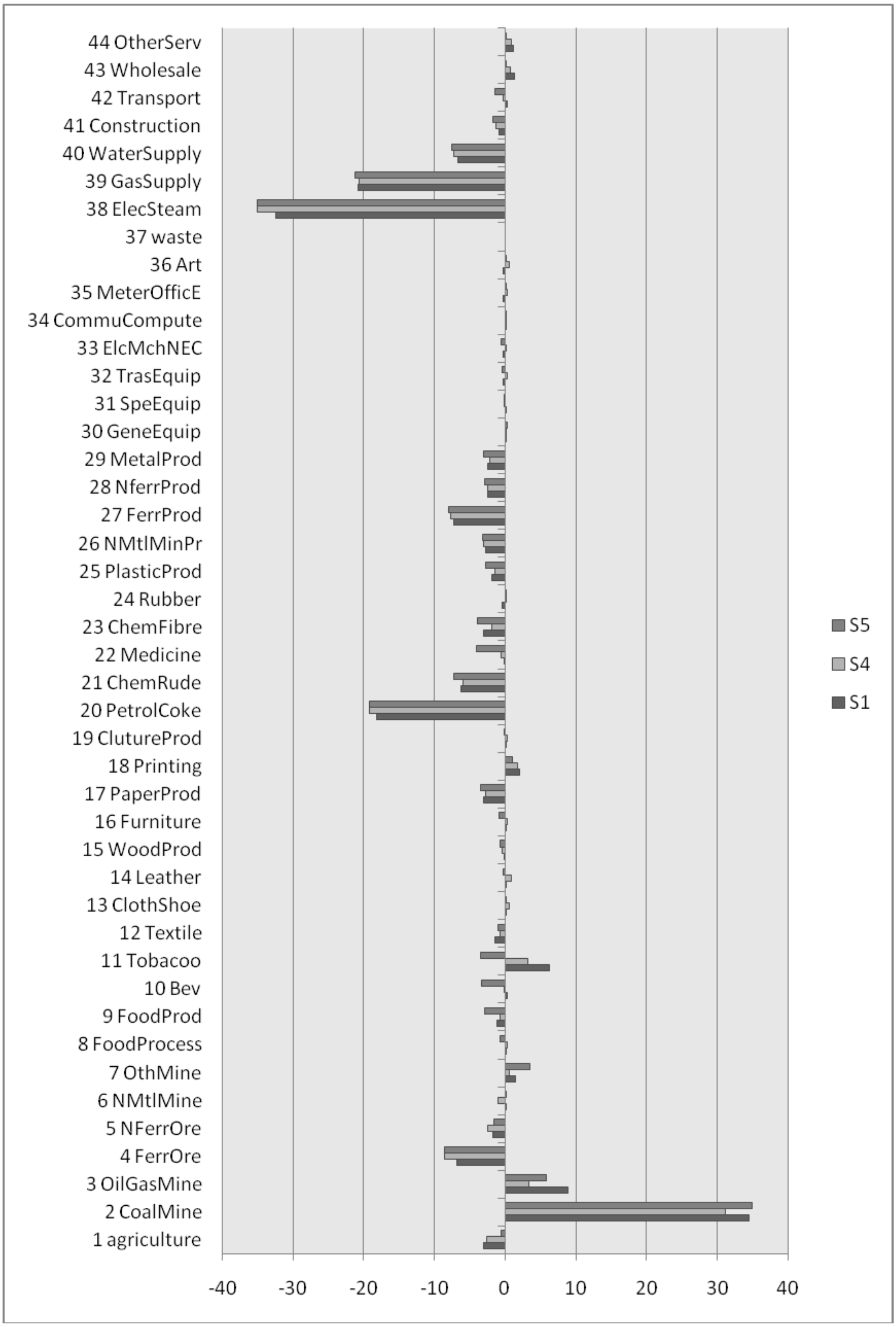
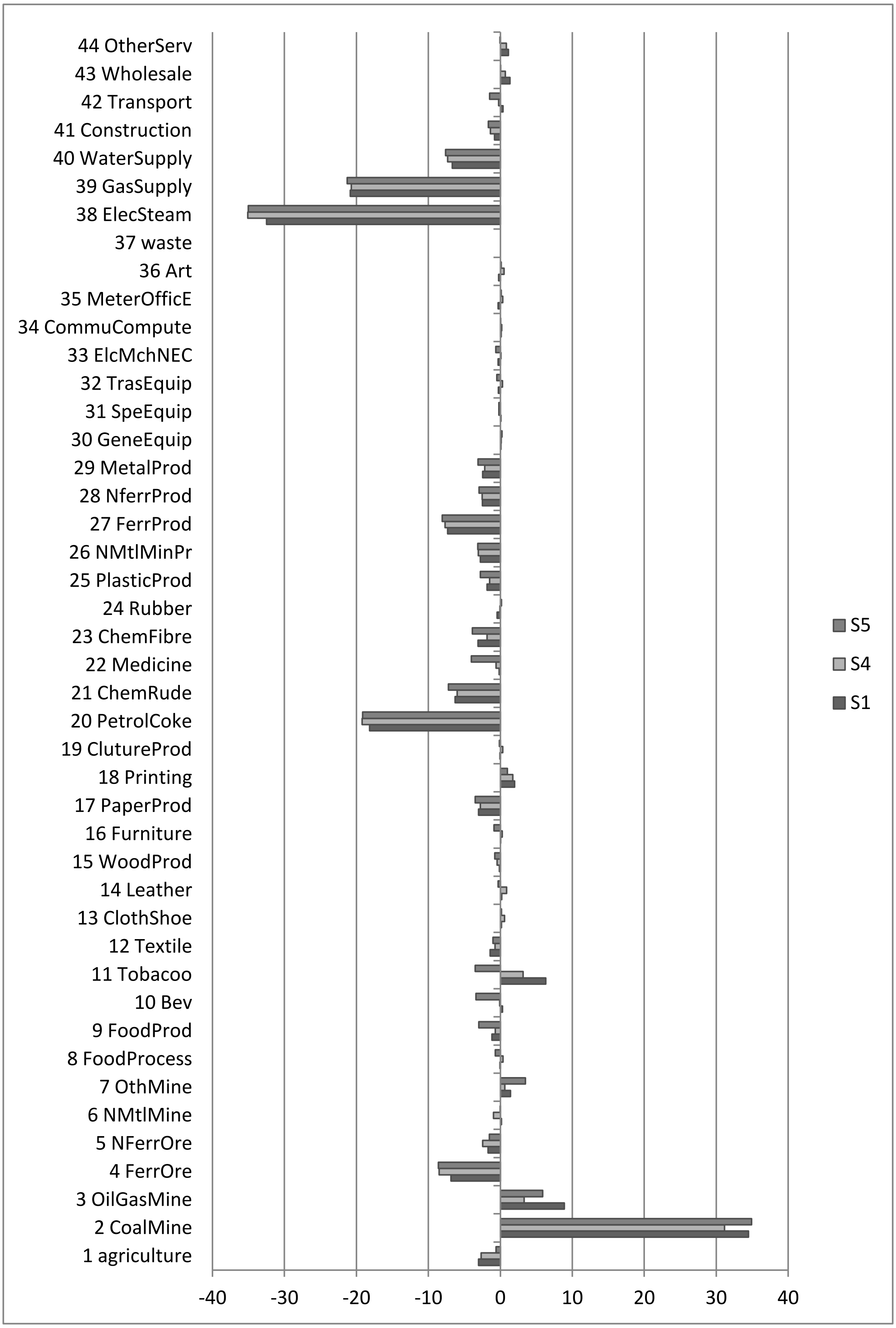


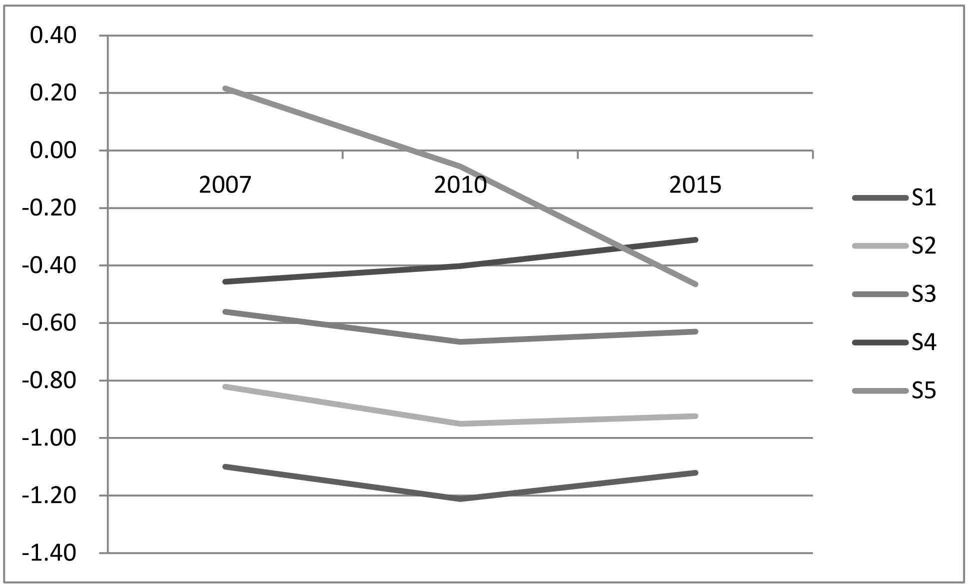
Figure 6. Export change comparison: S1, S4 and S5 (%)


44 OtherServ
43 Wholesale
42 Transport
41 Construction
40 WaterSupply
39 GasSupply
38 ElecSteam
37 waste
36 Art
35 MeterOfficE
34 CommuCompute
33 ElcMchNEC
32 TrasEquip
31 SpeEquip
30 GeneEquip
29 MetalProd
28 NferrProd
27 FerrProd
26 NMtlMinPr
25 PlasticProd
24 Rubber
23 ChemFibre
22 Medicine
21 ChemRude
20 PetrolCoke
19 CluturePro d
18 Printing
17 PaperProd
16 Furniture
15 WoodProd
14 Leather
13 ClothShoe
12 Textile
11 Tobacoo
10 Bev
9 FoodProd
8 FoodProcess
7 OthMine
6 NMtlMine
5 NFerrOre
4 FerrOre
3 OilGasMine
2 CoalMine
1 agriculture
-40
-30
-20
-10
0
10
20
30
40
S5
S4
S1

In terms of GDP impact, Figure 7 below shows that the long-term GDP impact of S1, S2 and S3 has similar trends, which will decrease after the introduction of the carbon price, and will slightly recover after 2010 (by considering the real 2008-2009 global economic crisis). Under S4, the negative GDP impact is much smaller and recovered quickly compared with other scenarios. The main reason is the return back of revenue to production, which would help to support production and help to reduce the negative impact on investment (Figure 9), and facilitate the recovery of capital stock, accompanied with the long-term assumption that employment would recovery to the base level (Figure 8).

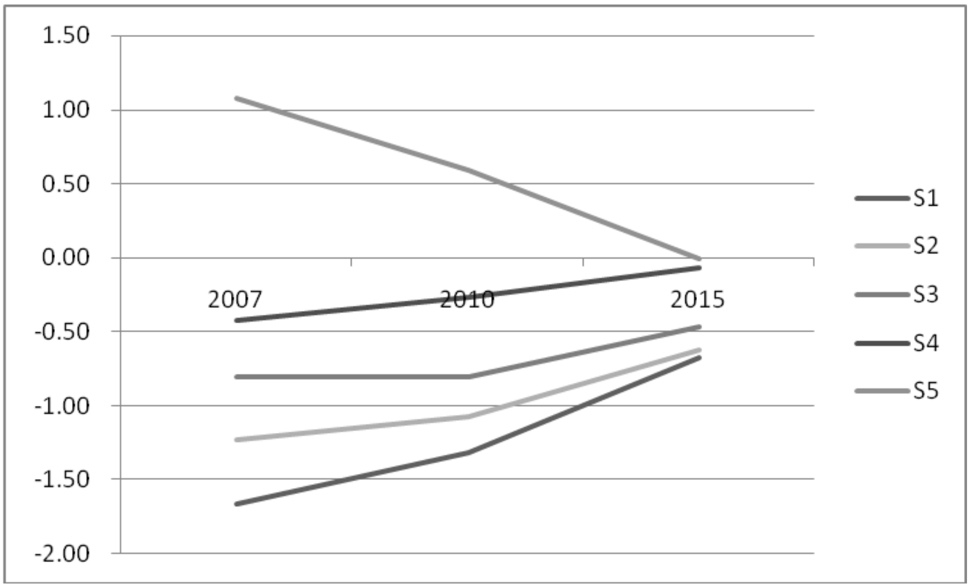
Another striking result is in S5, which is the most recommended scenario according to the short-term analysis, although the long-term GDP impact is decreasing over the long-term. This is principally due to the following reason: the decreasing price of consumption goods increases the demand for consumption which generates substitution effect among different investments and exports. The price of investment products therefore increases, and engenders a decrease of the real return of capital and thus reduces the demand for investment. This finally leads to a decrease more of capital stock relative to other scenarios, which contributes to a GDP growth decrease together with a decreasing employment.

Figure 7. Long-term GDP impact of RMB 100/tCO2 among scenarios (%)



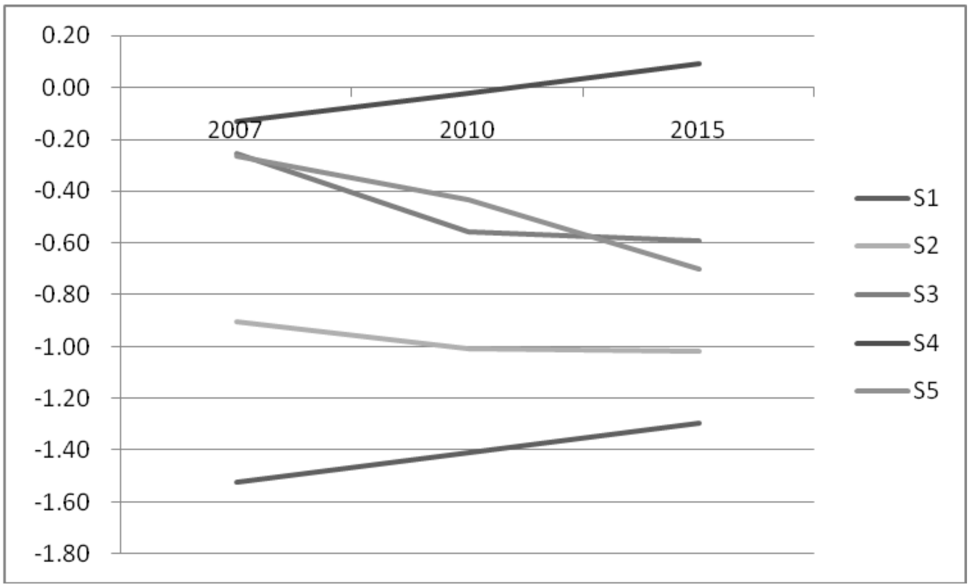
Source: SIC-GE.

Figure 8. Long-term employment impact with a carbon price of RMB 100/tCO2 (%)



Source: SIC-GE.

Figure 9. Long-term investment impact with a carbon price of RMB 100/tCO2 (%)



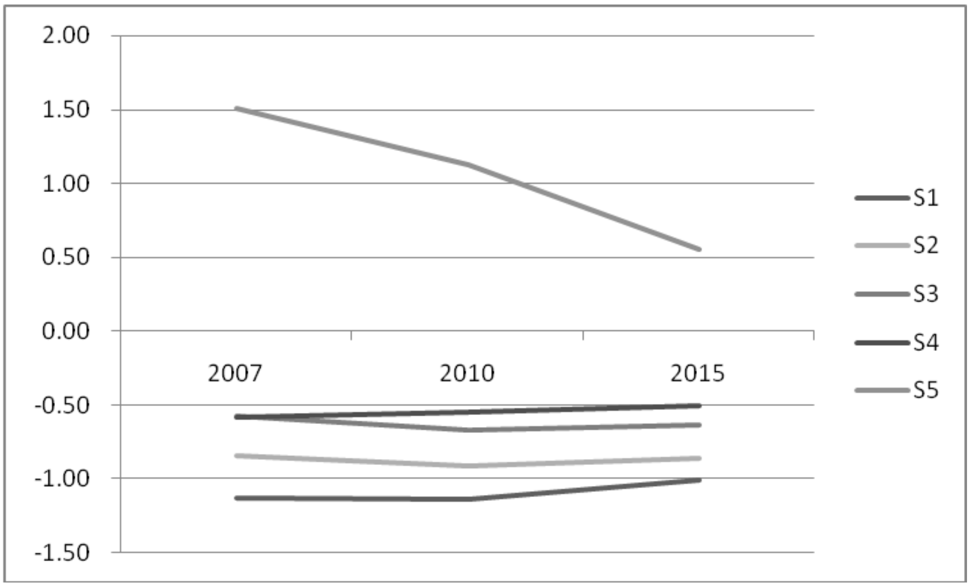
Source: SIC-GE.

Figure 10 shows the long-term consumption impact. The consumption impact is similar among S1-S4 while it decreased under S5. The reason for the similar trend of S1-S4 which follows the movement of GDP is due to the assumption that the average propensity of consumption is fixed in the long term. For S5, despite the decreasing consumption, the positive value indicates that the revenue feedback to consumption always contributes to the increase of consumption (although the GDP variation changes from positive to negative).

Figure 11 shows the long-term export impacts. As shown, all scenarios will generate moderate export decreases with regard to the reference scenario. For S4, the revenue feedback to production will reduce the producer price of domestic goods, which will contribute to a recovery of exports in the long-term. For S5, the decreasing export trend is due to the increase of export prices as a result of increasing domestic consumption.

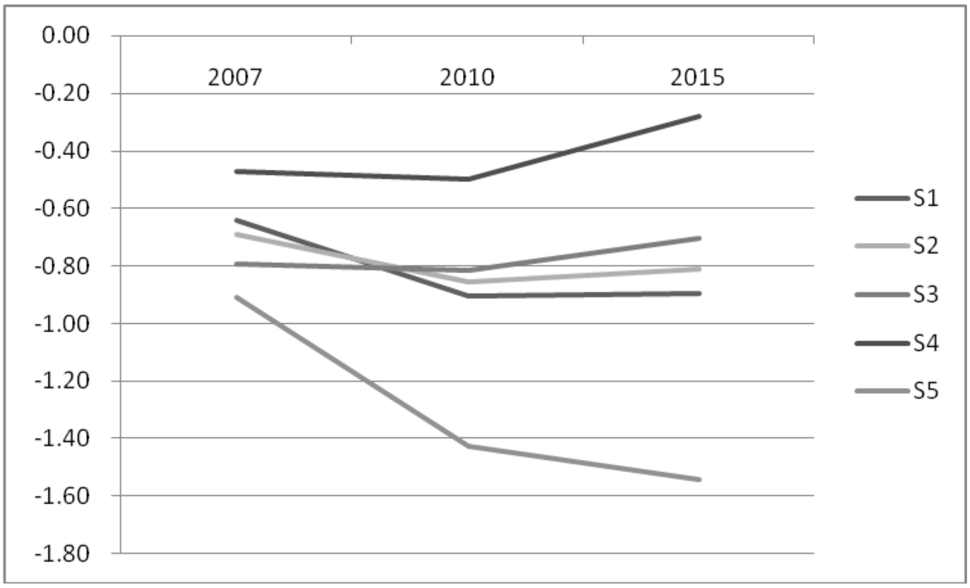
Finally, in terms of total CO2 emissions reduction (Figure 12), all five scenarios follow the same trend. This is primarily due to the same technological change assumed by the model for these scenarios.

Figure 10. Long-term consumption impact of a carbon price of RMB 100/tCO2 (%)



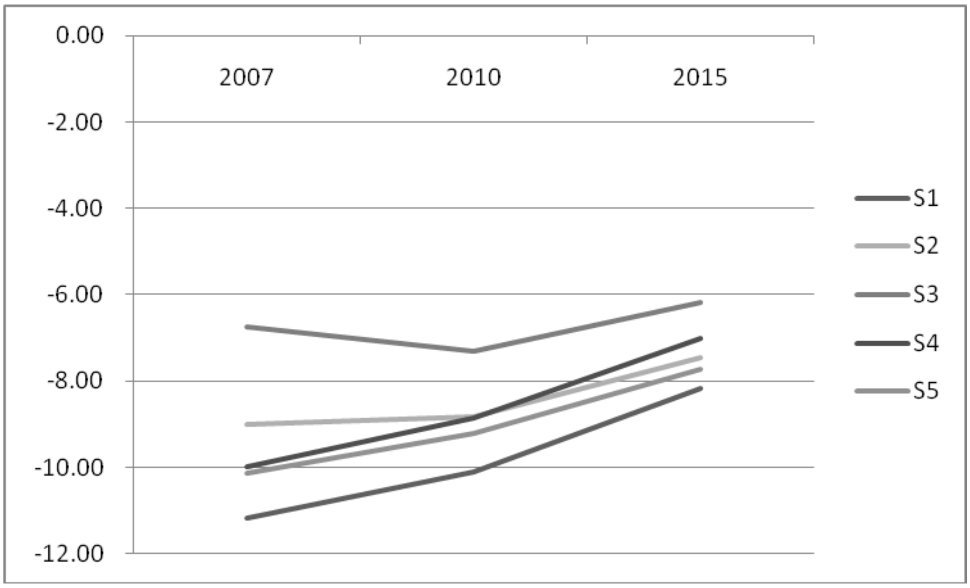
Source: SIC-GE.

Figure 11. Long-term export impact of a carbon price of RMB 100/tCO2 (%)



Source: SIC-GE.

Figure 12. Long-term CO2 emissions impact with a carbon price of RMB 100/tCO2 (%)



Source: SIC-GE.

5. Conclusion

This paper has adopted a CGE modeling analysis by using the China SIC-GE model which has also been used to undertake several policy-oriented quantitative assessments for the Chinese government. By providing the economic and climate impact of the higher carbon price of RMB 100/tCO2 (roughly 11-12 euro/tCO2 or $A 16/tCO2) under different revenue redistribution scenarios where the revenue is not redistributed, where the revenue is redistributed through subsidies on the electricity price, or is used to reduce production tax or sales tax in consumption commodities, the modeling analysis has provided additional important information for policy making, quite apart from the linear static analysis which policy makers have normally applied. The following points are noteworthy.

(1) Key contributing sectors to CO2 emissions reduction: The model has shown that the electricity sector would be the major contributor to CO2 emission reductions under a carbon pricing policy. For example, under the scenario S1, total CO2 emissions would decrease 661 million tones, of which 428 million tones of CO2 would be reduced from the electricity sector in 2007 based on real sectoral CO2 emissions data. Ferrous metal, basic chemical, coal mining as well as some other energy-intensive sectors are also major contributors of CO2 emissions reduction, after the electricity sector. This result corresponds to the higher share of carbon cost to sectoral value-added of these sectors that linear static analysis also showed. Further, the relatively limited numbers of principal contributing sectors of CO2 emissions reduction could provide a solid reference when deciding the coverage issue of carbon pricing policies, whether in the form of an emission trading system or a carbon tax. Instead of implementing national wide carbon pricing policy, the carbon price could be assigned to a limited number of energy-intensive sectors and could achieve more or less the same emission reduction target while imposing less administrative and management costs.

(2) Sectoral output changes and compensatory measures: The model has demonstrated the sectoral output and export changes with a carbon price of RMB 100/tCO2. As shown, under the same scenario S1, most energy supply sectors' output decreased dramatically while the output of industrial sectors (including energy-intensive sectors such as ferrous metal, basic chemicals, etc.) decreased within a range of 1-2%. At the export level, most of the energy-intensive sectors' export decreased dramatically yet

certain sectors' exports increased due to an export price decrease. The carbon pricing policy could therefore contribute to China's development strategy of curbing the expansion of domestic energy-intensive sectors and the export of energy-intensive products. However, for certain sectors, compensatory measure(s) might be important if a higher carbon price is implemented. For example, the export of the metal product sector could be reduced by more than 4% according to the model results. The products of this sector usually possess higher value-added and longer process chains, and therefore the exemption of a carbon price on their exports might be helpful. Further research work should therefore focus on specific sectors which could require different compensatory measures if a higher carbon price is implemented.

(3) Revenue redistribution under a Chinese institutional context: This paper shows that the scenario where the revenue generated by carbon pricing is redistributed to stimulate production or consumption seems to be the most efficient option in terms of welfare and cost-effectiveness among options analyzed in this paper. Even without such a revenue redistribution system, the regulated electricity price could also be seen as a subsidy to the economic system, which would reduce the negative impact of carbon pricing. Although there is so far no specific (tax or fiscal) revenue redistribution mechanism in China, considering that the taxation and fiscal system is undergoing reform, developing such a redistribution fiscal system could have major economic benefits for China..

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Annex A. Sector division and statistical compatibility of data

In China, sectors are currently classified under the statistical standard GB/T4754-2002[46]. Similar to the NACE system, sectors are designated by a higher case letter, indicating the section name, followed by three numbers: there are 20 sections (from A to T), the first number, which ranges from 1 to 98, indicates the division, the next number represents the group, while the final number further divides the groups into classes. Under GB/T4754-2002, the 2007 Chinese Economy Input-Output (IO) Table divides into 135 sectors. To facilitate our analysis and for clarity, these 134 sectors were consolidated into 36 representative groups for the analysis using the approach developed by Hourcade et al. (2007), as shown in Table A1. The sectors shown are defined according to GB/T4754-2002 down to the group number level. Certainly, the 36 sector division is statistically compatible to and an integrated form of the 44 sector division that ESY used. The only difference between these two sector divisions are that certain service sectors under 44 sectors division were merged into one sector under the 36 sectors division for analytical simplicity, given their low energy consumption levels.

According to the 2007 IO table of the Chinese economy, the sector value-added is obtained from the "total value-added" row, and the total Chinese GDP is given by the sum of the sectoral value-added. Sector turnover is obtained from the corresponding "gross output" column, and export and import values are obtained from the "exports" and "imports" columns for each sector. The value of imports is calculated according to the CIF (Cost, Insurance and Freight) price plus custom duty, and the exports are measured by the FOB (Free On Board) price. All values refer to 2007 producer prices,

46 See National Bureau of Statistics of China for detailed information. http://www.stats.gov.cn/tjbz/

which includes value-added tax (which is different to the *System of National Accounts* (SNA) 1993).

Table A1. Consolidated sectors, classifications according to GB/T4754-2002 (down to group number)

Sectors	Sectors under GB/T4754-2002
Agriculture, Forestry, Animal Husbandry, Fishery and Water conservancy	A1-5
Coal mining and washing	B6
Oil and gas exploitation	B7
Ferrous metal mining	B8
Non-ferrous metal mining	B9
Other mining	B10-11
Food and tobacco	C13-16
Textile	C17
Clothing, leather and product	C18-19
Lumber and furniture	C20-21
Pulp & Paper	C22
Printings and media recording	C23
Education and sport product	C24
Petroleum refining, coking and nuclear materials production	C25
Basic chemicals	C26
Drugs	C27
Chemical fibre products	C28
Rubber products	C29
Plastic products	C30
Non-metallic mineral products	C31
Ferrous metal	C32
Non-ferrous metal	C33
Metal products	C34
Mechanic equipment	C35-36
Transportation equipment	C37
Electronic equipment and machinery	C39
Communication, computer and other machineries	C40
Apparatus, cultural and office equipment	C41
Other manufactures	C42-43
Electricity & Heat	D44

Gas production and supply	D45
Water production and supply	D46
Construction	E47-50
Transport and stock	F51-59
Trade, accommodation and restaurant	H63,65; I66-67
Other services	G60-62; J68-71; K72; L73-74; M75-78;N79-81;O82-83; P84; Q85-87; R88-92; S93-97; T98

Annex B. Energy and CO2 data

Table B1 gives related data of carbon content and combustion rates. In 2007, 82.9% (2,722.9 TWh) of electricity generated came from thermal power plants (National Bureau of Statistics and National Energy Administration, 2009).

Table B1. Unit carbon content and combustion rate of major fossil fuels in China

	Coal	Coke	Oil	Gasoline	Kerosene	Diesel	Fuel Oil	Gas
Carbon content (tC/TJ)	25.8	29.2	20	18.9	19.6	20.2	21.1	15.3
Combustion rate	0.9	0.9	0.98	0.9	0.98	0.98	0.98	0.99

Annex C. Framework for model result explanation

Based on the definition of the marginal product of labor and capital, equations C1 and C2 can be obtained as follows:

$$RW = \frac{P_{GDP}}{T*P_C} * MPL(K, L) \quad (C1)$$

$$ROR = \frac{P_{GDP}}{T*P_I} * MPK(K, L) \quad (C2)$$

where RW denotes the real wage, ROR denotes the real rate of return of capital, P_{GDP} denotes the GDP deflator, P_C denotes the consumption price, P_I denotes investment average price, MPL and MPK denote respectively the marginal product of labor and capital which are a function of labor L and capital K, T denotes the power of general tax on GDP.

(C1) and (C2) can be written by the percentage change form as equations (C3) and (C4). The variables noted in lower case indicate the percentage change form of the relative variables in (C1) and (C2).

$$\mathrm{rw} = \mathrm{p}_{\mathrm{GDP}} - \mathrm{p}_{\mathrm{C}} + \mathrm{mpl}(\mathrm{k},\mathrm{l}) - \mathrm{t} \quad \text{(C3)}$$
$$\mathrm{q} = \mathrm{p}_{\mathrm{GDP}} - \mathrm{p}_{\mathrm{I}} + \mathrm{mpk}(\mathrm{k},\mathrm{l}) - \mathrm{t} \quad \text{(C4)}$$

For the marginal product of labor or of capital, the percentage change form can be obtained by adopting CES (Constant Elasticity Substitution) function. This leads to the final form as follows:

$$mpl = \frac{S_k}{\sigma}(k - l) \qquad \text{(C5)}$$

where, $S_k = \dfrac{\delta K^{-\rho}}{\delta K^{-\rho} + (1-\delta)L^{-\rho}}$, and $\sigma = \dfrac{1}{1+\rho}$.

S_k can be seen as the ratio of capital return on total primary return (mainly GDP) and σ denotes the substitution elasticity.

Furthermore, the policy shock can be assumed to generate no effect on technology progress in the short term. The percentage change of GDP (in percentage forms given by lower case letter) can be written as follows (by omitting the change of tax revenue):

$$\mathrm{gdp} = \mathrm{S_L} \times \mathrm{l} + \mathrm{S_K} \times \mathrm{k} \qquad \text{(C6)}$$

where gdp, l and k denote respectively GDP, labor and capital changes, $\mathrm{S_L}$ and $\mathrm{S_K}$ denote respectively the share of labor and capital to GDP.

Roughly according to the SIC-GE model estimation, there were about 5.77 billion ton CO2 emission from the primary energy consumption and imported secondary petroleum product. A carbon cost at RMB 100/tCO2 could generate RMB 577 billion, which would account for about 2.17% of total GDP (RMB 26,581 billion) in2007.

According to (C3) and (C5), by assigning 2.17% to t, a small relative change of the GDP deflator on consumer price level (pg-pc=-0.01%), with the general substitution elasticity at 0.5, the share of capital at 0.535 (calculated according to the data in row 8, Table 1), with the short-term fixed real wage assumption, the change of employment is obtained at -2.03%, which is close to the model result -1.66%. The difference is caused largely by the industrial structure change due to the higher impact of carbon costs on the energy-intensive sectors.

According to (C6), if the capital stock is assumed to be indifferent to the carbon cost in the short term, the change of GDP will be generally generated by the unemployment. As a result, the GDP loss according to the simplified framework reaches roughly to 0.77%. This is lower than the result of the model (-1.1%), as the simplified framework does not account for the welfare loss due to the implementation of the carbon pricing policy (carbon tax).

Part 4: Carbon pricing for China's electricity sector

(2) Institutional analysis of introducing an emissions trading system to China's power industry

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Summary

This paper first analyses the carbon emission trends and projections in China's electricity sector, with a view of highlighting the importance of this sector in any future effective emissions trading scheme in China. The paper then reviews various ETS models worldwide, with a focus on how electricity generation and usage is handled in each of these different countries and regions. This is followed by an analysis of China's electricity institutional framework, and then by analyzing three options for introducing emissions pricing into the power sector and thereby integrating China's electricity sector into a future ETS. For each option, the advantages, disadvantages and institutional constraints are discussed. The paper concludes that any complete cost effective ETS would require a carbon price on both the supply side and the demand side. Further, regulatory and institutional reform of the electricity sector is urgently required, especially price liberalisation, and that low-carbon electric power policy should be developed as part of a whole sector liberalization policy package.

With 24.1% of the world's total carbon dioxide emissions in 2010 (IEA data), China has become the world's largest carbon emitter, and the second largest electric power producer. Electricity generation is the largest carbon dioxide emissions sector in China, accounting for 44% of total carbon emissions in 2010. In the coming decade, the scale of China's power industry will continue to expand significantly. Thus, the success of emissions reduction in the power sector will be crucial for reducing the government's targeted carbon emissions intensity of its GDP by 40-45% by 2020 from its 2005 level, and promoting its climate change mitigation goals. The power sector is therefore at the heart of China's climate change challenge.

As an internationally recognized major carbon emitting sector, electric power has been included in all international emissions trading systems, which are regarded internationally as the most effective market instrument to achieve least cost emissions abatement and significantly reduce carbon emissions. Given China's very large power sector, it is therefore vital for this sector to be included in China's carbon market, and that an effective emission trading scheme be established in China. However, the world's ETS experience is built on competitive power markets and cost based (cost pass through) pricing systems. In contrast, China's power industry is subject to a government fixed price system, and this sector is only at a very early stage of transition towards a market-based competitive mode. In this situation, the existing equal share power dispatch system and highly regulated pricing system in China has created obstacles for any introduction of emission trading.

Thus, to what extent the electricity sector will be included in China's upcoming carbon market will have considerable impact on the design, implementation and performance of China's ETS. Several domestic studies have confirmed that the emission reduction potential of the electricity industry is mainly in the supply side. However, in the current design in several pilot ETS schemes in China, which are planned to commence limited operation in 2013, only indirect emissions on the power consumption (demand) side are considered. Such designs are a compromise given the current state fixed pricing policy in the electricity sector, and as such, these will not have a substantive impact on the pilot and national long-term power investment and emission trends.

In this analysis, three options are identified for introducing emissions pricing in the power sector and integrating emission trading into the broader program of power sector institutional reform. These options differ in terms of policy intervention, prices, and the level of electricity supply and demand responses, but they recognize that for a carbon trading market to include the power sector and be effective, the existing highly regulated retail pricing system policy would need to be reformed and made flexible. This would have to involve the linking of retail electricity prices with power purchase costs that ensure a cost and price pass through further downstream activities.

To explore carbon abatement potential in the electricity sector, the most effective way under an ETS is to impose a price on both the supply side and the demand side, especially the supply side where the carbon intensity of a power generation unit is mainly determined by the electricity dispatch order. To reflect the emission cost of different generation units in the dispatching merit order, this can be achieved either through a top-down command and control regulation such as “energy saving dispatch” or “low carbon dispatch”, or though the combination of a competitive power market and carbon market model. The analysis concludes that the development of an efficient lower carbon power system in China is heavily constrained by the existing power industry institutional structure and state fixed retail price system, and that a lower carbon power policy could only be introduced as part of whole sector reform package aiming at further liberalization of the electricity sector in China.

1. Introduction

Climate change is a global challenge that needs a global response (Metz and Intergovernmental Panel on Climate Change., 2007). The changing climate is characterized by an increasing global average temperature, which is mainly due to historical cumulative emissions from human activities. The only way that we can cope with climate change is to reduce emission in the future. As the largest emitting country, China has recognized the importance of climate change, and has mainstreamed this climate mitigation objective within its development policies. In 2009, China announced its national action to reduce its CO2 intensity per unit of GDP by 40-45% from the 2005 level by year 2020. China’s climate change mitigation and emissions abatement goals have been included in its 12^{th} Five Year Plan for National Economic and Social Development (12^{th} FYP, 2011-2015) adopted by the National People’s Congress, the highest legislation authority in China. In 2011, a national mid-term mandatory target for 2015 was announced to reduce carbon dioxide emission per unit GDP by 17% and energy consumption intensity by 16% compared with 2010 levels, and this national emissions intensity target was subsequently disaggregated down to the provincial level with emission intensity reduction targets varying from 10% to 21% (most provincial emission intensity targets varied within the range of 17.0 - 19.5%).

This low carbon clean energy development strategy is a great challenge for China as its economy had experienced a two-digit growth rate for about two decades. China’s energy related CO2 emissions have tripled in past twenty years. According to China’s second national strategy paper on climate change, in 2005 China’s total GHG emission was approximately 7.467 Gt CO2 eq of which carbon dioxide accounted for 80.03%, methane for 12.49%, nitrous oxide for 5.27%, and fluorinated gases for 2.21% respectively. The total net GHG removed through land use change and forestry was about 421 Mt CO2 eq. Therefore, by deducting that amount removed, China’s total net GHG emission in 2005 was around 7.046 Gt CO2 eq, of which carbon dioxide accounted for 78.82%, methane for 13.25%, nitrous oxide for 5.59% and fluorinated gases for 2.34% respectively.

From a sectoral perspective, excluding land use change and forestry, China's GHG emissions from energy activities, industrial processes, agricultural activities and waste treatment were 5.769 Gt CO2 eq, 768 Mt CO2 eq, 820 Mt CO2 eq and 111 Mt CO2 eq respectively in 2005, accounting for 77.27%, 10.26%, 10.97% and 1.50% of the total GHG emission. The electricity sector was the major contributing sector in China's emissions, accounting for about 44% in the year 2010. Although China has implemented a package of ambitious policy to control emissions in China's electricity sector, the carbon emissions from the power sector is still expected to double over the next decade. During the China's 11^{th} Five Year (2006-2010), average annual growth rate of electricity production had reached 11.10%. China's electricity production in 2010 reached 420.8 billion kWh, ranking second in the world. However, China's electricity consumption per capita was only 2,943.5 kWh, still much lower than the OECD average. In the coming decade, the scale of China's power industry will continue to expand. Thus whether or not China can de-carbonize its power sector will have important implication for its combat effort to mitigate climate change (Baron et al., 2012).

Market-based instruments such as a carbon tax or emission trading have been regarded as important cost-effective means to promote greenhouse gas emissions reduction and to reduce the cost of reducing emissions of the whole society. As an important market mechanism, emissions trading is promoted for its theoretical potential to achieve an environmental goal at least cost, through an efficient allocation of efforts among energy sources to reduce emissions. In 1997, the total amount control and emissions trading of greenhouse gas was included in the Kyoto Protocol, which gave birth to the rise of emissions trading all over the world. Many countries and regions launched their own emissions trading system, some of which have been put into practice. The EU ETS (European Union Emissions Trading Scheme) (Ellerman and Buchner, 2007) started from 2005, the US RGGI (Regional Greenhouse Gas Initiative) started from 2009 (Hibbard and Tierney, 2011), Australia's NSW GGAS (New South Wales Greenhouse Gas Abatement Scheme) started from 2003, and Japan's Tokyo Metropolitan total amount control and emissions trading systems started from 2010 (Perdan and Azapagic, 2011). China has also launched two provinces and five cities as carbon market pilots, which will start in 2013 according to NDRC's plan (Lo, 2013). As an internationally recognized major CO_2 emission emitter, the electricity sector has been included by nearly all emissions trading systems internationally. But in contrast to other ETS in the world, China's electricity sector is still not fully liberalized. Although competition has been partly introduce into the wholesale market, the retail price in China is still largely under fixed price regulation.

This paper first examines the emission trends and projections of the Chinese electricity sector with a view to highlighting the importance of the electricity sector in any meaningful ETS in China. The second part of this paper reviews different practices of ETS worldwide, with a focus on how these electricity sectors are considered by different countries and regions. Then this paper considers three options for integrating the electricity sector in China's ETS program. For each option, both the advantages, disadvantages and institutional constraints are discussed. Lastly, we draw the conclusions.

2. China's Power Industry: Pricing and Dispatching

Regulatory reform in China's electricity sector began in year 2002, commencing with the removal of China's nationwide power monopoly and the creation of five regional power generation companies and two grid or transmission companies (Xu and Chen, 2006). The government also created a specific regulator, the State Electricity Regulatory Commission (SERC), as the main regulator over all commercial electricity in China. But the SERC was never given the right for planning and project approval. Key decision-making power is still held by the National Development and Reform Committee (NDRC), the key planning agency in China. In 2013, the new government announced the merging of SERC into the National Energy Bureau under NDRC. The regulatory reform system in China's power sector, though, is still very much a work in progress.

Electricity Pricing

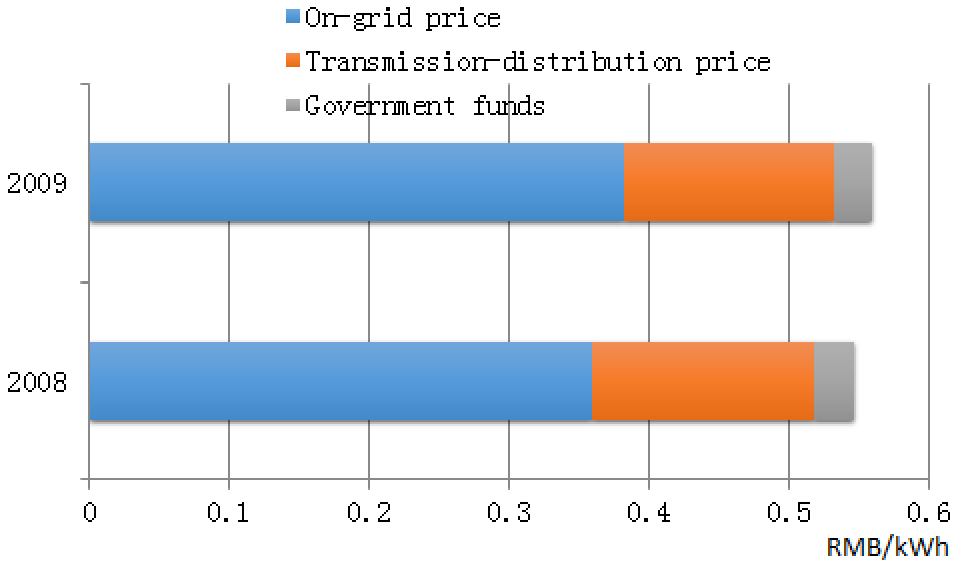
Although the ultimate objective is to introduce competition in both the wholesale and retail market, and to gradually allow prices to be more responsive to the market, the electricity pricing system is still highly regulated (Ma, 2011). Electricity price reform in China has experienced a long history, during which some important events are shown in Table 1.

Table 1: China's electricity price reform timeline

Data	Events
March 2003	The State Council approved the "power reform program"
March 2003	The State Electricity Regulatory Commission established
July 2003	The State Council promulgated the "power price reform program", determining the power price reform objectives, principles and major reform measures
March 2004	Promulgated the benchmark electricity price policy, uniformly formulated and promulgated the Pool Purchase Price of new production units in each province
December 2004	The National Development and Reform Commission promulgated a coal and electricity price linkage mechanism
March 2005	Promulgated 3 Interim Measures on Management of Pool Purchase Price , Transmission-distribution price and Electricity sales price
May 2005	The first coal-electricity price linkage
June 2006	The second coal-electricity price linkage, the adjustment of the various regions is between 1.5% and 5%
In 2007	"The Interim Measures for Allocation of additional revenue on Renewable Energy Power Prices"，"Small thermal power price cuts program"
July-August 2008	The third and fourth coal-electricity price linkage, where electricity prices were raised twice
October 2009	Development and Reform Commission and Electricity Regulatory Commission jointly made "several opinions on accelerating electricity price reform(Drafts)"
October 2010	Development and Reform Commission promulgated "Guiding Opinions on the Pilot Implementation of Tiered Pricing for Household Electricity(drafts)"
December 2012	Cancellation of the two-track system of thermal coal and power, and perfected the coal and electricity price linkage mechanism

In China, the electricity price is still highly regulated. The electricity retail price consists of several parts: the power purchase cost (wholesale generation price), transmission and distribution losses, transmission and distribution price and the cost of government funds. Generally, power purchase costs account for about 65% - 70% of the electricity sales price (see Figure 1). Moreover, government funds consist of the major national water conservancy project construction fund, the reservoir resettlement fund, the loan funds of rural power, additional city utilities, and the renewable energy power price surcharges.

Figure1: 1 Components of the electricity sales price



Source: SERC

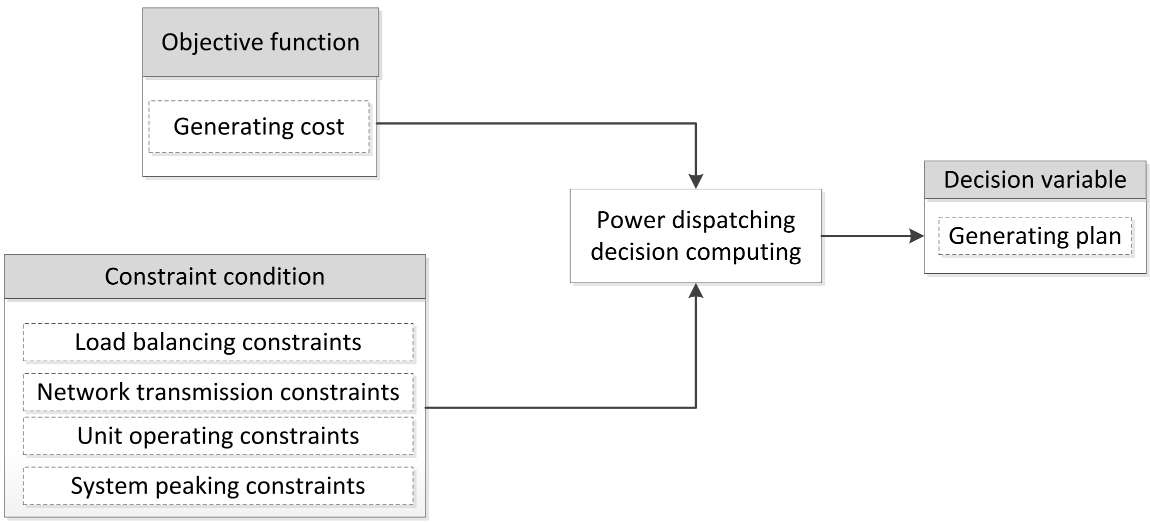
Both the wholesale generation price and the retail price are adjusted regularly based on several conditions. For most generation units, their price will be determined based on the sum of the average social cost, which is an estimate of the average construction and operating costs of different types of power plant. New power plants in the same grid area apply the same standard price. Since 2005, the wholesale generation price is also linked with the coal price because of the close correlation between the cost of coal and the cost of electricity generation. The linking mechanism is designed to trigger adjustment of wholesale generation price if the coal price volatility reaches a predetermined threshold. After 2005, China experienced a sharp increase of coal prices but the linkage between the coal price and the wholesale generation price was only adjusted three times (Peng, 2011). The reason is that the government was concerned about inflation (the CPI), which is partly driven by energy prices. Theoretically, electricity retail prices are also adjusted regularly by the adjustment of wholesale generation prices. But such price adjustments only apply to industrial and commercial consumers who take a higher retail price than the national average. For household and agricultural (rural) consumers, the electricity retail price is relatively stable and lower than the average power price. Thus, both wholesale generation prices and retail prices in China are not in line with energy costs. This has led to erratic investments, and periodic shortages in the supply of electricity. The most recent shortage happened in year 2011 when most generation companies lost money due to growing coal prices in that year.

China's dispatching system

The dispatching system is largely constrained by the huge number of contracts signed between generators and the grid company in the early stage of market reform (Kahrl et al., 2013). In that time, to provide incentives to capacity expansion serving the fast growing demand, grid companies signed fixed price and quota contracts with investors to reduce their risk and attract more investment. Those contracts always included both predetermined price and volume quotas. Thus the dispatch system began to change from an economic dispatch to "equal share dispatch" (Ciwei and Yang, 2010). After the peaking of power generation investment, the grid company assigned roughly equal numbers of operating hours to each contracted units to make sure their contract will be implemented smoothly and steadily.

Such equal share dispatch is contradictory to the principle of economic dispatch (see Figure 2), as it means that the less efficient generation units will be operated similarly to those more efficient ones.

Figure 2 structure of traditional power dispatching

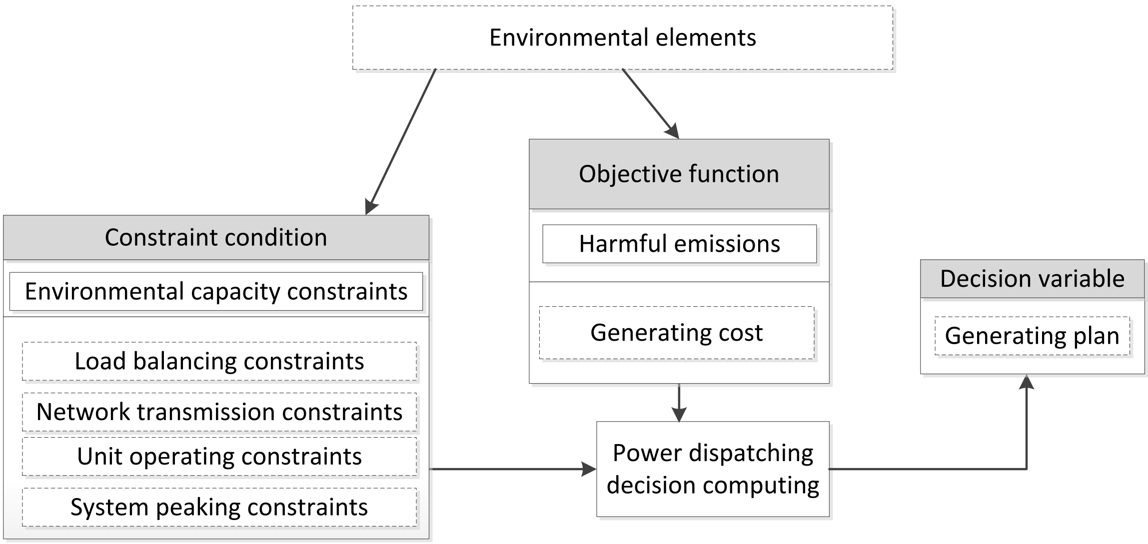


China began piloting energy-saving power dispatching from the end of 2007, on the premise to ensure a reliable supply of electricity, with the principles of energy conservation, economy, and the dispatching of renewable generation resources taking priority (Ciwei and Yang, 2010). In the energy-saving dispatch, the generation units are ranked according to their energy consumption and pollutant emission levels. The operator will then call different generation units in turn, with a view to minimizing energy and resource consumption and pollutant emissions (See figure 3).

The merit order of energy-saving power dispatch is as follows:

(i) The renewable energy generators without ability to regulate, such as wind, solar, ocean energy and hydropower:
(ii) The renewable energy generators with ability to regulate, such as biomass and geothermal energy, and landfill and waste generator units which meet environmental requirements;
(iii) Nuclear power generation units;
(iv) The coal-fired co-generation units providing "constant heat supply“;
(v) Natural gas, coal gasification generator units;
(vi) Other coal-fired generator units;
(vii) Fuel oil generator units.

Figure 3 structure of the energy-saving power dispatching



Both the regulated pricing system and the institution constrained dispatching system pose challenges and opportunities for emission reduction in China’s electricity sectors. There are institutional shortcomings which may lead to obstacles when introducing an emission trading scheme into the electricity sector. But once these are overcome, significant short-term potential can be achieved through the combination of price responsive demand and improved efficient dispatch on the supply side. Several countries and regions have introduced emission trading in the electricity sector. Those lessons and experiences learnt from international practice may bring fruitful insight for China's on-going emission trading pilot programs.

3. International practice in emissions trading in the power industry

There are two types of emissions trading system. These are the Cap-and-Trade system based on allocation, and the Baseline-and-Credit system based on projects. This paper mainly focuses on Cap-and-Trade emissions trading system. A complete emissions trading system should include several key aspects, such as a cap on emissions system, allowance allocation system, trading system, flexible mechanisms, MRV system and a penalty system. The following part will introduce several emission trading systems in the power industry from the above aspects (except NSW GGAS). Further, as emission trading is used in the power industry, this paper also focuses on several aspects related to electricity, such as the power market, the dispatching mode, and the electricity sales price adjustment

EU ETS

The EU ETS is a cornerstone of the European Union's policy to combat climate change and its key tool for reducing industrial greenhouse gas emissions cost-effectively. The first and still by far the biggest international system for trading greenhouse gas emission allowances, the EU ETS covers more than 11,000 power stations and industrial plants in 31 countries, as well as airlines. As a mandatory transnational Cap-and-Trade system, the EU ETS developed in three phases, during which coverage, emission reduction targets and design details were different. (see Table 2)

Table 2: The three phases of the EU ETS

Phase	Emission reduction targets	Emissions cap (t CO_2e)	Coverage industry	Controlled gas
1st trading period (2005-2007)	45% of the targets promised by the Kyoto Protocol		Energy production and energy-intensive industries	CO_2
2nd trading period (2008-	6.5% less than in 2005	2.098 billion	Aviation industry added	CO_2

2012)				
3rd trading period (2013-2020)	20% less than in 1990	1.846 billion	Chemical, Ammonia & aluminum etc added	N_2O, PFC_S added

The EU ETS initially took a grandfathering-free distribution method, in which the allowance allocated by Member States in the way of auction should not exceed 5%. In the 2nd trading period, the allowance allocated in the way of auction was increased to 10% and paid distribution became the basic allocation method. In accordance with the requirement of the EU, all Member States set up a national registration platform, maintaining a high degree of consistency. In addition to this, there is a separate centralised registration platform at the level of EU, linking registration platform of all countries. After the establishment of the EU ETS, the EU built many Climate Exchanges, such as the ECX (European Climate Exchange), Nord Pool (Nordic Power Exchange), and so on. As for flexible mechanisms, Banking, Borrowing and Offset have been used in the design of the EU ETS. The EU Act No. 87 of 2003 required monitoring and reporting system for greenhouse gas emissions to be included in the framework of the EU ETS. Later, the EU launched a Monitoring Report Guideline, used for monitoring, reporting and certification of greenhouse gas emissions data. The EU emissions trading directive required imposition of fines beyond the allowed emissions allocation.

EU Member State have a liberalized electricity market, nearly all of which has the same framework, such as generation side bidding, generation/transmission/ distribution separation, and transmission network open to the third party, to develop the electricity market. Power users can freely choose to buy electricity from the local distribution and sale of electricity companies or other companies. To help building a genuinely free internal market for electricity, the EU electricity systems has no independent dispatching agency, but it has a Transmission System Operator (TSO). The TSO is required to ensure a smooth technical operation of the system and to facilitate the development of the electricity market. Every Member State and region has its TSO. After the start in 2005, the EU ETS made a visible impact on the EU's power industry, which can be broadly divided into four areas. That is, it increased production costs for power generation, rapidly increased the electricity market price, substantially increased power generation's corporate profits and stimulated investment in energy technology and innovation. Especially in the case of the second area, as the

European electricity market is basically a liberalized competitive market, the rising cost of carbon pricing can be reflected in an increasing competitive wholesale electricity price. The electricity price continuously rose from 2010 to 2012.

US RGGI

The Regional Greenhouse Gas Initiative (RGGI) is the first market-based regulatory program in the United States to reduce greenhouse gas emissions. RGGI is a cooperative effort among the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont to cap and reduce CO_2 emissions from the power sector. RGGI requires about 233 fossil fuel-fired electric power generators with a capacity of 25 megawatts (MW) or greater in the region to join in this initiative. As a regional Cap-and-Trade system, RGGI started from January 1, 2009. Its emissions reduction target is to leave existing emissions unchanged from 2009 to 2014 and to reduce emissions by 10% from 2015-2018. Its emissions cap is about 0.17 billion t CO_2.

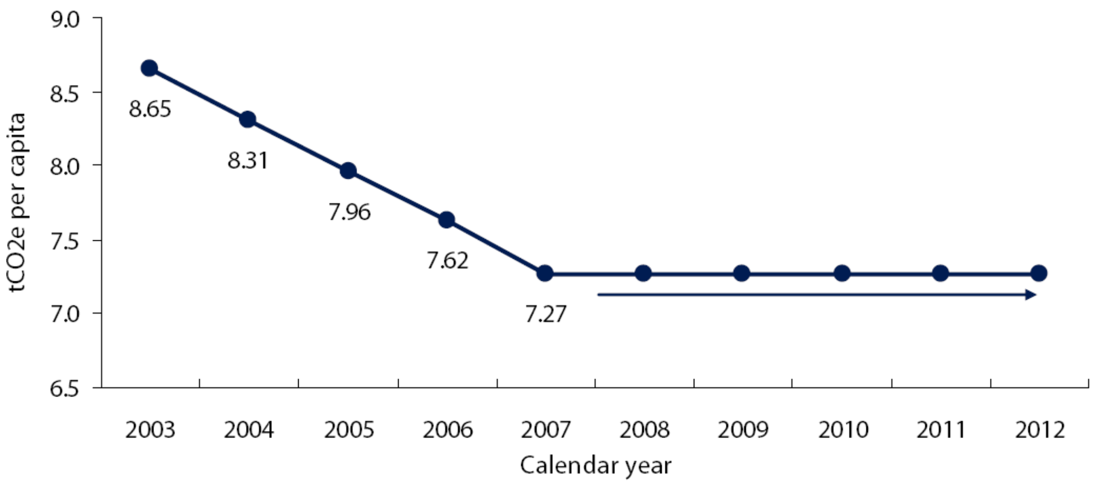
The RGGI allocates CO_2 allowances by quarter. Firstly, by allocating all allowances to the member states through a grandfathering-free distribution method, and then allocate to each state through CO2 allowance auctions, in which each auction units for 1000 allowances. The initial auction was in the manner of a single-round, uniform price and sealed bid auction. Later, on the premise of maintaining a uniform auction, the auction can be converted to undergo several rounds of price rises. Any unsuccessful auction allocations will go to the next auction, with the market prices in the following auction as reserve price. According to the provision of RGGI, all control objects must install the necessary monitoring system and report monitoring data to regulatory agencies quarterly. In order to enhance performance capabilities of control objects and ensure a steady allocation market and price, RGGI use flexibility mechanisms, such as carbon offsets, extending the compliance period, safety valve trigger mechanism, and the carbon offset trigger mechanism. RGGI states have selected a professional independent market regulator – Potomac Economics – which is responsible for the supervision of the primary market auction and subsequent secondary market activities.

RGGI covers a range of electricity markets, including the New England electricity market, the New York electricity market and the PJM operating area of New Jersey, Delaware and Maryland. The cost of carbon emissions allocations will be delivered to the terminal of the sale price of electricity, but it has little effect on the promotion of a rising sale price of electricity. According to the RGGI's economic model, RGGI implementation is expected to result in a sales price rise of 1% to 3%. Furthermore, RGGI implementation will change the competitiveness of the different types of units in the electricity market, and some coal-fired power plants may not be able to compete in the market.

Australia NSW GGAS

The NSW Greenhouse Gas Reduction Scheme (GGAS) commenced on 1 January 2003. It is one of the first mandatory greenhouse gas emissions trading schemes in the world. GGAS aims to reduce greenhouse gas emissions associated with the production and use of electricity. It achieves this by using project-based activities to offset the production of greenhouse gas emissions. The GGAS is the only mandatory 'baseline and credit' type emissions reduction system in the world now. Specific set of benchmarks can be seen in Figure 4.

Figure 4: Carbon emissions baseline values, 2003-2012



GGAS require emission reduction obligations for the sale of electricity (electricity retailers), including all retail electricity license holders, power generation supplied directly to retail consumers, and market consumers which buy electricity directly from the national electricity market, rather than from electricity production (power generation companies). The GGAS transactions commodity is called NGAC (NSW Greenhouse Gas Abatement Certificate) and abatement certificates equal one tonne of CO_2 equivalent emission reduction credits. There are three major abatement certificate provider behaviors, which is to reduce the carbon intensity of electricity production, to reduce power consumption or to improve energy efficiency and the management of CO_2 in the atmosphere. At the end of 2008, GGAS produced a total of 91.37 million abatement certificates. The management of GGAS is responsible to the Independent Pricing and Regulatory Tribunal, which has two special functions, compliance and scheme administration.

Australia's national electricity market is a mandatory electricity market, in which market management requires that power generators with installed capacity greater than 50 MW must bid for the sale of electricity to the power pool. Retailers and large users purchase electricity from the power pool through the transmission and distribution network in accordance with the market price.

Comparison of different emission trading systems in the power sector

In order to clearly identify the differences between different carbon emission trading systems in the power sectors, Table 3 compares these differences from the following perspectives: emission reduction targets, allowance allocation, MRV, enforcement mechanisms, trading system, flexible mechanisms, electricity market, and the electricity dispatch and sales price (see Table 3).

The following principles applied across all the trading systems:

(i) For a cap-and-trade system, allowance can be allocated free early, but there is a risk that over-allocation may happen;
(ii) Developed to a certain stage, an auction allocation is more effective.
(iii) Comprehensive legislation is a prerequisite and guarantee of the emissions trading system's effective operation.
(iv) After emissions trading commenced, the cost of electricity generation will generally increase, and eventually this is passed down to the sales price.

Table 3 Comparison of different emission trading system in the international power industry

	Emission reduction targets	**Allowance allocation**	**MRV**	**Enforcement mechanisms**	**trading system**	**Flexible mechanisms**	**Electricity market**	**Electricity dispatch**	**Sales price**
EU ETS	6.5% less than in 2005; 20% less than in 1990	Firstly free grandfathering allocation, later auction allocation	Monitoring Report Guideline	EU emissions trading directive	Climate exchange	Banking, Borrowing and Offset	Generation side bidding, gen/ trans/distrib separation	Has no independent dispatching agency, but has TSO	Market price
RGGI	2009-2014: maintain same 2015-2018: reduce by 10%	State: free Grandfathering, Generator: auction	All have installed monitoring system, report quarterly	RGGI Inc. responsible	Auction platform run by RGGI Inc.	Carbon offsets, extend period, safety valve trigger , carbon offset trigger	Electricity sales price judged by market		Market price
NSW GGAS	2003-2007: reduce emissions capita from 8.65 to 7.27 t CO_2e	Distributed by the share of electricity sales	Independent Pricing and Regulatory Tribunal	Independent Pricing and Regulatory Tribunal	Market platform		Generation side bidding, gen/ trans/distri separation		Market price

4. Introducing an emissions trading system to China's power industry

The NDRC agreed to establish pilot ETS in Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong and Shenzhen in 2011. Beijing, Shanghai and Guangdong, whose design and work programs covered the power sector, have settled on their initial designs of key ETS features (see Table 4). As pilot carbon emissions trading has not yet commenced, it is still not possible to assess the impact on the pilot's electric power sector.

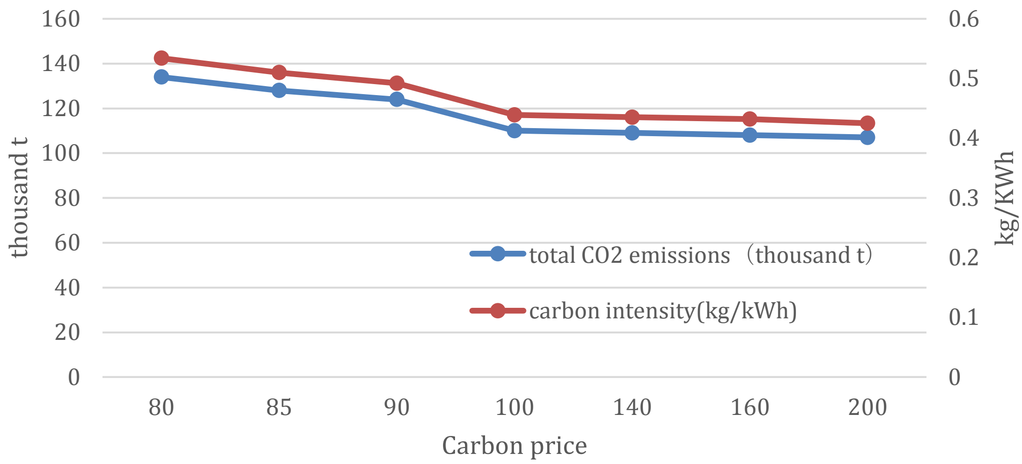
Table 4: Comparison of the Beijing, Shanghai and Guangdong ETS plans and designs

Pilot	**Beijing**	**Shanghai**	**Guangdong**
Period	**2013-2015**	**2013-2015**	**2013-2015**
Industry	Power, heat supply, thermal power supply, manufacturing, large public buildings	Power, iron and steel and other industries Aviation and other non-industrial	Power, cement, petrochemical and other industries
Participating subjects	2009-2011 average annual CO_2 emissions ≥10,000 t,	2010-2011 any average annual CO_2 emissions ≥20,000 t	2011-2014 average annual CO_2 emissions ≥20,000 t,
Traded products	Direct and indirect CO_2 emissions CCER	Mainly CO_2 emissions allowance, project-based greenhouse gas emission reductions as a supplement	Mainly CO_2 emissions allowance, project-based greenhouse gas emission reductions as a supplement
Allocation allowance	Partially free (grandfathering), a small part of auction	During the pilot free, timely auction,	Partially free (grandfathering), a small part of auction

The first challenge of introducing an emission trading system to China's power industry is the regulated electricity pricing system. As an economic instrument, the basic feature of cap and trade is to internalise the environmental externalities of greenhouse gases. After the emissions trading, the cost of electricity generation should be increased, and eventually this cost is passed through to the electricity retail price.

However, at the moment, both wholesale and retail electricity price are regulated, under which it will be difficult to internalise costs associated with emissions. The second challenge is the equal share dispatching system. Now, the most commonly used dispatching mode is still the traditional dispatching, based on the local government's annual plan, which specifies the number of hours each power plant should run. In this case, emissions allowances will be difficult to trade. Thus, in the pilot cities and provinces, if the electricity sector is subjected to a stringent cap, they will have significant interaction with the existing pricing regime and dispatching system. The detailed design of several provincial pilots is still under development and has not been released to the public. But most pilot cities and provinces have decided to cover the electricity sector within their emission trading scheme. Thus the key issue is how to set the level of the cap and the stringency of the cap for the electricity sectors.

Figure 5 Stringency of the cap and level of the carbon price



The short-term relationship between the stringency of the cap and level of the carbon price is based on a provincial case study and is illustrated in Figure 5. It can be seen that a more stringent emission cap will be translated into a higher carbon price, and then a much higher electricity price for both wholesale and retail. In the longer term, a high carbon price can give incentives for low carbon investment in the power sector and will further increase the share of low carbon generation units in the whole mix. However, it is still not clear how different pilot programs will consider the level of cap on electricity sector. There seems to be an emerging consensus that an intensity-based cap might be preferred among local government decision makers. However, it can be expected that the emissions cap for the electricity sector will initially be lax to avoid possible conflict with existing pricing and dispatching systems. But for a meaningful cap and trade system at the national level, an ambitious abatement goal will be the key for the success of emission trading. Thus the interaction and synergy between emission trading with existing policies in the power sector will be at the heart of the debate.

5. Options for the introduction of emission trading to the power industry

There might be different options available to create synergies between emission trading and existing policies in the power sector. Through the above analysis of different emission trading systems in the power industry, we can sum up three possible options for such synergies:

Option 1: Competitive Market Model

The first option is based on the policy practice in EU and in Australia where the electricity sector has been liberalized into a fully competitive market. In such models, the emission allowance will be allocated to power generation plants who will compete with each other through a bidding process in the wholesale market. The grid company will dispatch different generation units based on a least cost principle. The retail price will still be regulated before a further opening of the retail market, but the linkage between the retail price and the wholesale price will be strengthened. The frequency of adjustment on retail prices will be enhanced. There is still a time lag between the wholesale price and the retail price. But the advantage of such arrangement is to maintain the stability of retail prices while still passing price signals from the supply side to the demand side. The key requirement of this option is to deepen reform in the electricity sector with a view to establishing a competitive wholesale power market. The retail market can be under-regulated at a later stage, but a regular linkage between wholesale and retail price should be established.

Option 2: Low Carbon Dispatching Model

The first option largely depends on electricity reform enabling a more competitive power market. This market reform has met with roadblock in the past decade due to special interest conflicts between the central and local governments. The local government considers electricity generation as a major driver of their local economy, thus have always taken a conservative approach when considering to open their market to neighbouring competitors. Given this institutional shortcoming, a second option is to aim at changing from the equal share dispatch system to a low carbon dispatch without touching upon vague power market reform measures. In such a model, the emission allowance will be allocated to power grid companies which are responsible for dispatching. The power market will still be regulated, but the dispatch will be based on the principle of minimal emissions. The low carbon dispatch will increase the power purchase cost of grid companies, thus it also needs to link the retail price with the wholesale price to offset the additional costs from the grid company and to transfer price signals from the generators to the consumers. Compared with the previous model, this model is not deeply constrained by power market reforms, but would still need to resolve their long-term contracts signed between generators and grid companies. Thus, a compensation plan for those sunken investment cost will be important for the acceptance of this model.

Option 3: Demand Side Levy Model

Both option 1 and option 2 needs a substantial change of existing policies in the electricity sector, although the level of policy change will be different. Without changing existing policies, it is still possible to partly introduce emission trading in the power sector. The Tokyo city carbon market is the only carbon market so far at the city level in the world. In the Tokyo carbon market, the emission allowance is allocated to final consumers based on their electricity consumption. The Tokyo model is an interesting case because it will not change existing market structures in the power sector while still covering emissions from the power sector indirectly. The Tokyo model has received attention in the design of several pilot programs because it avoids a substantial policy change in the power generation sector. The carbon price will be collected as an additional cost from the final consumers, thus it will not touch existing wholesale and retail pricing system.

Challenge and Barriers for Different Options

The introduction of emission trading in the electricity sector can unlock the abatement potential for a more efficient and less carbon intensive power sector. It is important to ensure that power market reform should help rather than hinder the trend of introducing ETS in the China’s power sector. Thus, both challenges and obstacles faced by the different options should be carefully analyzed.

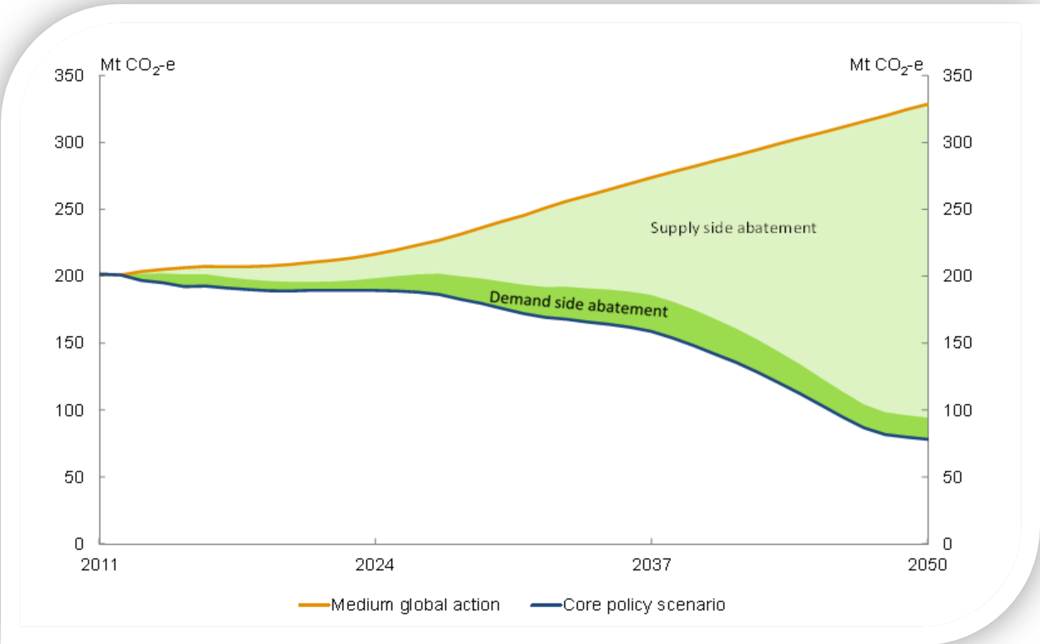
For the competitive market model, it is a more mature model that can be observed worldwide. The competitive market model depends on a fully functional competitive power market which could be centralised or decentralised based on its technical, historical and political features, but this is still absent in China at present. Nevertheless, a transparent and rule-based dispatch system is an essential element for efficient market operations. An effective power market should include a transparent, rule-based dispatch system and a cost pass through mechanism that reflects costs in all their components. Thus the competitive model is only applicable within a broader framework and process of electricity price and institutional reform.

Without touching existing market structures as a whole, it is still possible to introduce emission trading through a low carbon dispatch model. China has tested a new dispatch system entitled “Energy saving dispatch” in five provinces. Implementation of this dispatch methods favour those most efficient generation technologies, and so far this has achieved significant energy saving and CO2 reductions in pilot provinces. This energy saving dispatch method can be further amended, and changed into a low carbon dispatch method, which takes into consideration new and forthcoming CCS power plants in the future. Although the low carbon dispatch model is a feasible alternative within the current power regulatory context, it is still facing the same potential barriers as the energy saving dispatch pilots. Thus it is difficult to expect implementation at the national level.

The demand side levy option is the least policy intervention options, which mainly focuses on the potential and price responsiveness on the demand side. The growth of electricity demand is the biggest challenge for China's energy and climate goals. A consumer responsibility design can avoid substantial power industry policy change. However, the shortcoming of such a design is also clear: the emissions abatement potential on the demand side only accounts for a minor share of the abatement potential in the electricity sector (see Figure 6). Moreover, without price signals for investors, the long-term transition towards a low carbon generation mix will highly depend on other policies such as renewable and nuclear expansion plan.

Figure 6 Potential and response in demand and supply side

Source: Australia Government (2011)



There is interaction and synergy between emissions trading policies and regulatory reform policies in the electricity sector. A successful and meaningful emission trading scheme depends on further regulatory reform towards a cost based electricity pricing system at both the supply and demand side. Emissions trading policies cannot be successful if they are only regarded as an isolated policy reform measure. The essential point of emission trading is to give a price for carbon emission, thus it should be regarded as a part of broader policy package for energy and resources price reform.

6. Conclusions

Accounting for over 40% of total CO_2 emissions in 2010, electricity generation is the largest CO_2 emissions sector in China. Thus to what extend the electricity sector will be included in China's upcoming carbon market will have considerable impact on the design, implementation and performance of China's ETS. Several studies have confirmed that the emissions reduction potential of the electricity industry is largely on the supply side. In the current designs of several pilot schemes in China, only indirect emissions on the consumer side are considered. Such designs are a compromise with current pricing policies in the electricity sector, but these will not have a substantive impact on the long-term power investment and emission trends.

To explore the full abatement potential in the electricity sector, the fundamental way is to impose a price on both the supply side and the demand side, especially the supply side where the carbon intensity of unit generation is mainly determined by the dispatch order. To reflect the emission cost of different generation units in the dispatching merit order, this can be achieved either through a command and control regulation such as "energy saving dispatch" or "low carbon dispatch", or though the combination of competitive power market and a carbon market model. For both models, the key is to couple retail electricity prices with power purchase cost that can ensure a cost and price pass through to the downstream.

It will be difficult to introduce an ETS in the power sector without deepening the reform of the power industry, especially existing pricing policy which is characterized as regulated retail price. Thus we conclude that low-carbon power in China is heavily constrained by progress in the power sector reform, and any low-carbon power policies should be considered as part of a whole policy package aimed at further liberalising the electricity sector in China.

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Part 4: Carbon pricing for China's electricity sector

(2) Increasing China's coal-fired power generation efficiency – Impact on China's carbon intensity and the broader economy to 2020

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Summary

The efficiency of China's coal-fired electricity generation has improved rapidly in the past decade. This improvement was achieved through the installation of more efficient large scale coal-fired electricity generation capacities and the forced closure of smaller-scale generation plants (2005-2011, 80.28 GW in capacity). Although the pace is slowing down, the trend is likely to continue, especially giving the Central Government's commitment to reduce the ratio of carbon emission to GDP (emissions intensity). In this study, the economic, financial, and environmental impact of China's coal-fired electricity efficiency improvements were analysed, and the most-likely and other scenarios of this efficiency improvement in future years were simulated.

The analyses showed that improved coal-fired electric plant efficiency led to higher employment in the short run and a higher capital stock in the long run relative to the baseline, which was the case without improvements in efficiency. This reinforced the direct positive impact of the improvement in efficiency on GDP. Although a higher GDP is a factor that dampens the emission-reduction effects of the improvement in efficiency, overall, the improvement in efficiency leads to a lower CO2 emission relative to the baseline. In the most-likely scenario, a continued improvement in efficiency over four years leads to an increase in real GDP of 0.15 per cent and a decrease in CO2 emission of 1.2 per cent in the long-run relative to the baseline. This policy instrument has the positive impacts on both economic growth and emission reduction.

The higher GDP and the GDP equivalent of the emission reduction relative to baseline form a future income stream – the gain from the investment made by choosing larger and more efficient power generation units. The net present value of this income stream calculated with a 5 per cent discount rate is estimated to be higher than the amount of investment required financing the improvement in efficiency.

Judging from China's policy of adopting more efficient technology and the technological potential of larger and more modern designed coal-fired power generation, improvement in coal-fired electricity generation efficiency is likely to continue to be one of the effective instruments for China to reduce CO2 emission, while maintaining a sustainable growth in the coming decade.

1. Introduction

China's current carbon dioxide abatement polices are engineered to achieve two sets of national targets, both written in terms of carbon dioxide emissions per unit of GDP, or carbon intensity for short. The 12th Five Year Plan (FYP) targets a 17 per cent reduction of carbon intensity from 2010 to 2015; the country's Copenhagen commitment, on the other hand, targets a 40 to 45 per cent reduction of carbon intensity from 2005 to 2020. During the country's 11th FYP, from 2006 to 2010 China reduced its carbon intensity by 19.1 per cent. This implies China needs to aim for a further 10.6 to 18.1 per cent reduction from 2015 to 2020[47].

To understand how China could achieve these targets, it is critical to understand what factors have been driving the country's carbon intensity changes in the past. A body of literature has attempted to identify such driving factors over the past 30 years. Three key messages that emerge from this literate are: 1) changes in carbon intensity has been primarily driven by changes in energy intensity (Chen, 2011); 2) changes in energy intensity has been primarily driven by changes in energy efficiency (Ma and Stern, 2008) and 3) changes in energy efficiency has been primarily driven by changes in thermal power efficiency (Li, 2011). Linking these messages, it suggests that changes in China's thermal power efficiency have been critical to changes in the country's carbon intensity over the past 30 years.

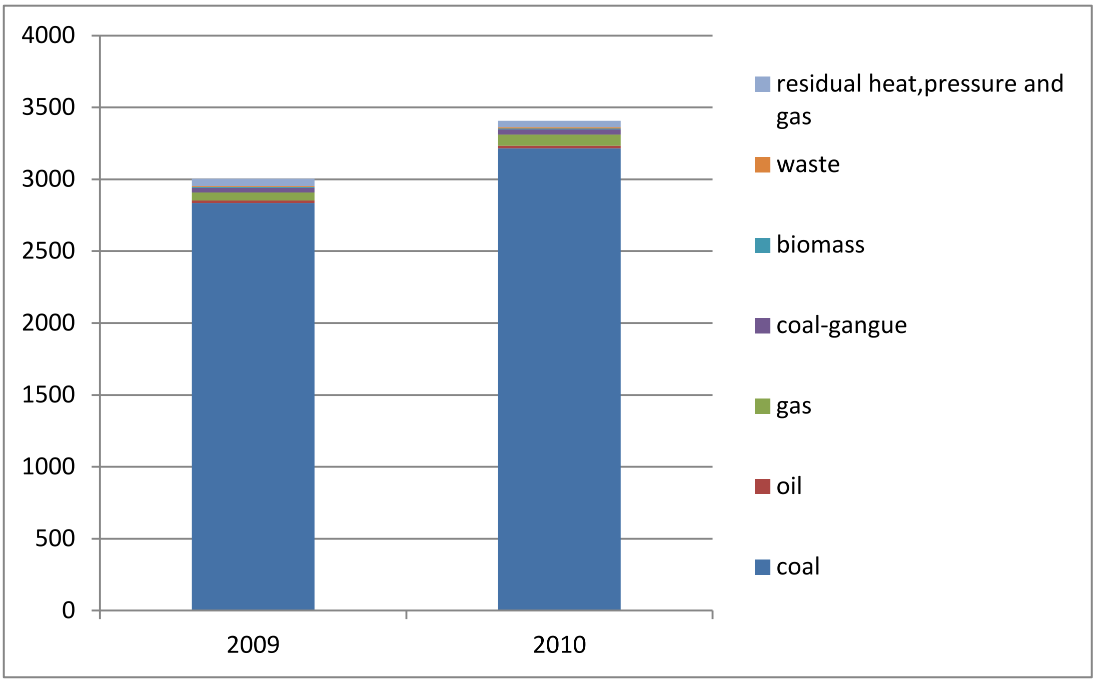
Therefore to understand how China could achieve its carbon intensity targets, it is critical to understand how the country's thermal power efficiency might change in the coming years to 2020. The changes in thermal power efficiency can be represented by changes in coal-fired power generation efficiency, since coal-fired power generation constitutes almost all thermal power generation in China (see Figure 1).

China's policies on coal-fired power generation have had profound implications on the industry's efficiency. Figure 2 shows the correlation between carbon intensity of GDP, energy intensity of GDP and the growth rate of coal-fired power generation efficiency in China from 2000 to 2009. The two horizontal lines show China's carbon and energy intensities of GDP. The two lines closely track each other and they are both in an inversed-V shape, i.e. the intensities increased in the early years of the

[47] Or, based on the 2010 intensity level, assuming a 17 per cent reduction by 2015, and another 32.6 to 38.2 per cent reduction to meet the 40 to 45 per cent target, respectively.

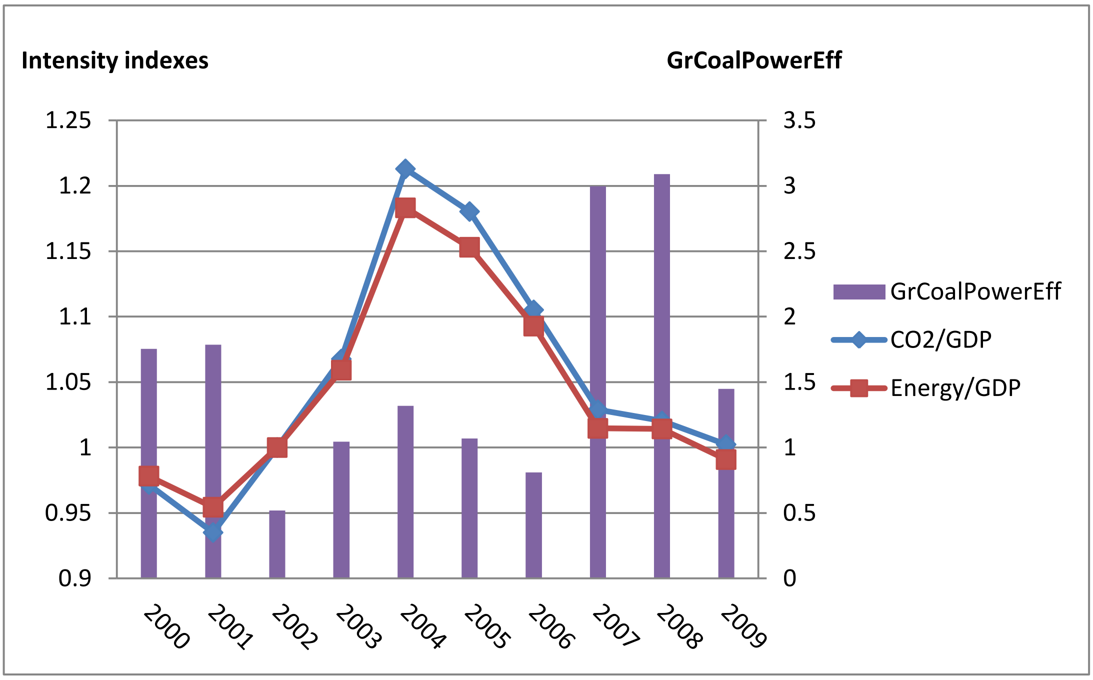
decade, peaked in the middle and fell to their respective beginning of the decade levels by the end of the decade.

Figure 1: China's thermal power generation by source, TWh



Source: China Electricity Council (2011)

Figure 2: Carbon intensity, energy intensity and coal-fired power generation efficiency growth in China



Note: carbon intensity and energy intensity are normlised to be 1 in 2002

Source: Carbon intensity and energy intensity (EIA, 2012); thermal efficiency growth rate: China Electric Power Year Book (2003) and China Electricity Council (2011).

The shape of these lines largely coincides with the policy shifts and efficiency changes in China's coal-fired power industry. The vertical bars in Figure 2 show the growth rate of efficiency in China's coal-fired power generation. From the late 20th century to the early 21st century, China already had plans to phase out small and inefficient (SAI) thermal power plants. During that time plants of unit capacities below 50 megawatt (MW) were branded as SAI and were set to be closed. As is shown in the early years in Figure 2, efficiency improvement was relatively fast and the intensities were relatively low.

However, as the country entered the WTO and began to endorse an investment-led and export-oriented growth model, it suffered a large power-supply shortage. Due to this shortage, starting from 2003, the closure of SAI units slowed down. China's 10th FYP originally targeted the closure of 13 gigawatt (GW) SAI capacities but in the end it only achieved 8.3 GW. As a result, only 50 per cent of power generating assets was above 300 MW units by 2005. In Figure 2, it is evident that the rate of efficiency improvement dropped between 2002 and 2006, which contributed to the rise in the intensities.

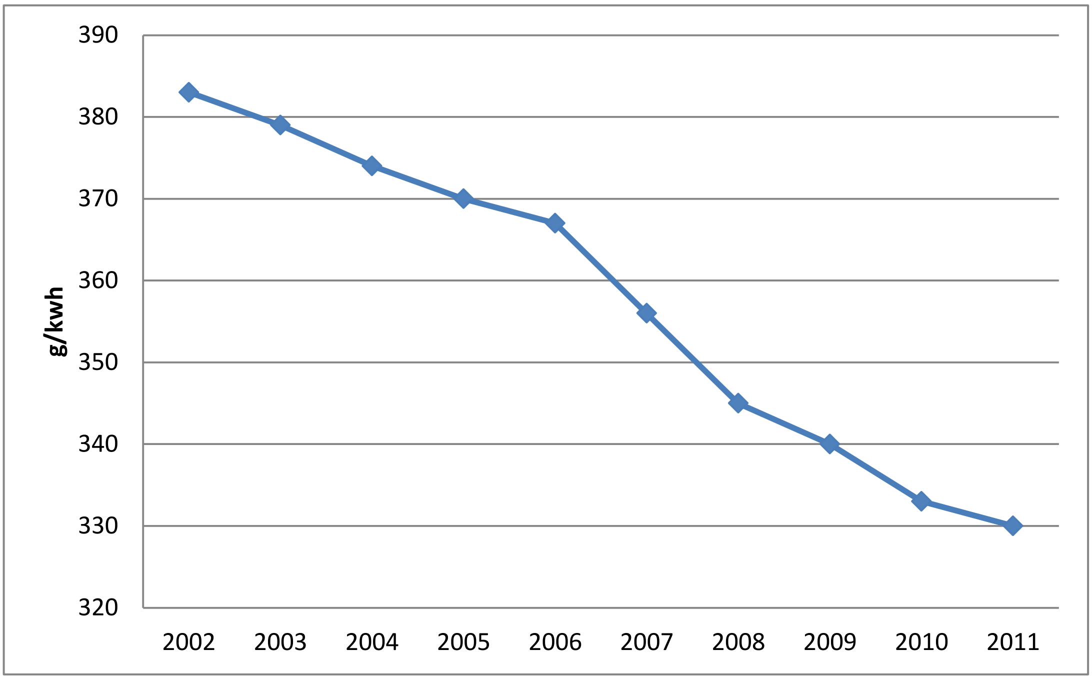
Then as China's environmental challenges became acute and the need to transform the growth model became inevitable, in early 2007, policies targeting the closure of the SAI units were reinstated. The most notable policy is the Large Substitute Small (LLS) campaign that mandates that old SAI capacities (below 200 MW) should be replaced by new, large and efficient capacities (above 300 MW per unit). The campaign is largely deemed as a success. China's 11th FYP targeted a closure of 50 GW SAI capacities but in the end it successfully closed 76.8 GW. As a result, 70 per cent of power assets were above 30 MW units by 2010. Thus we see in Figure 2 that the rate of efficiency improvement picked up towards the end of the decade, and the intensities also fell roughly to their respective beginning-of-the-century levels.

This study models the impact of efficiency improvement in coal-fired power plants on China's economy and its carbon intensity of GDP. Section 2 looks into different levels of efficiency improvement in the power industry. Section 3 uses a simple "back of the envelope" model to calculate the impact of efficiency improvement. This works as a check to see if CGE simulation results are plausible and also shows the implications of adding further considerations in the CGE analysis. Section 4 uses a CGE model to simulation the impact of efficiency improvement. We also use the CGE model to simulate the impact of a policy package that enhances efficiency through additional investment and which in turn is financed by taxation. We then observe both the macro-level results and the industry-level results. Section 5 concludes the research paper.

2. Coal-fired power generation efficiency

Different coal-fired power generation efficiency scenarios are projected in the policy years (between 2012 and 2020). These scenarios indicate a range in which the rate of efficiency improvement might evolve in the policy years. The efficiency measure used in this study is 'grams of standard coal used to supply per kilowatt-hour electricity to the grid'. Such data are available from the China Electric Power Yearbook of various years (see Figure 3). Six efficiency scenarios are devised, namely 1) Constant, 2) Post-WTO-trend, 3) 11th FYP-trend, 4) 12th FYP-target, 5) Cutting-edge and 6) Most-likely.

Figure 3: Coal-fired power plants efficiency: standard coal per kilowatt-hour electricity supplied to the grid[48]



Source: China Electric Power Yearbook (2003), China Electricity Council (2011).

Scenario Constant assumes no efficiency change in the power generation industry in the policy period. This is a highly unlikely scenario, but it serves as the baseline scenario against which the impact of other levels of efficiency change can be compared with. Thus the efficiency levels in 2015 and 2020 will be the same as it in 2011, at 330 g/kWh.

Scenario Post-WTO-trend extrapolates the average efficiency improvement rate over the past ten years. This includes a period of relatively slower efficiency improvement at 1.061 per year between 2003 and 2006 and a period of relatively faster efficiency

[48] Data for all the figures are shown in the corresponding appendix.

improvement at 2.399 per year between 2007 and 2010. The overall average efficiency improvement rate between 2003 and 2010 was 1.730 per year, i.e. every year 1.730 grams of standard coal will be saved in supplying 1 kWh of electricity on to the grid. Thus if the efficiency improvement rate follows the post-WTO trend in the policy years, the efficiency level will reach 308 g/kWh and 282 g/kWh in 2015 and 2020, respectively.

Scenario 11^{th} FYP-trend extrapolates the average efficiency improvement rate over the period of most progressive efficiency improvement between 2006 and 2010. The average efficiency improvement rate over the 5 years was 2.08 per year. Following this trend power efficiency will reach 303 g/kWh and 273 g/kWh in 2015 and 2020, respectively.

Scenario 12^{th} FYP-target takes the efficiency improvement targets set forth in the 12^{th} FYP. The targeted efficiency levels by 2015 and 2020 are 325 and 315, respectively, implying the rate of efficiency improvement needed are 0.38 per cent per year between 2012 and 2015 and 0.62 per year between 2016 and 2020.

Scenario Cutting-edge tries to find the fastest rate of efficiency improvement obtained from engineering-based studies. We rely on an IEA (2011) report as a rough guide for such efficiency levels. This report suggests the highest possible average efficiency in coal-fired power plants might be 320 g/kWh and 288 g/kWh in 2015 and 2020, respectively. These efficiency levels imply China’s efficiency improvement rates should be 0.77 per cent per annual between 2012 and 2015 and 2.09 per cent per annual between 2016 and 2020.

Most of the effort has been devoted to formulating the Most-likely scenario. As closure of old SAI capacities and building new large and efficient capacities has had a profound impact on overall power generation efficiency, the Capacity-composition Scenario details the probable capacity composition over the policy years. In formulating such a scenario, four pieces of information were sought: 1) the latest capacity composition before 2012; 2) the capacity composition of newly commissioned plants, 3) the unit efficiency of different plant sizes and 4) total new capacities to be put into use over the policy years.

Table 1: Capacity composition and unit efficiency, 2010

Single plant capacity (10MW)	Classification	Total capacity (10MW)	Capacity share	Efficiency (g/kWh)
100	non-SAI	3300	0.048	286

60	non-SAI	22247	0.321	292
[30-60)	non-SAI	24857	0.358	334
[20-30)	SAI	5201	0.075	350
[10-20)	SAI	6072	0.088	380
[0.6-10)	SAI	7672	0.111	420
Total weighted average efficiency: **333**		non-SAI efficiency:		**312**
		SAI efficiency:		**388**

Source: Productivity Commission (2011)

The latest capacity composition obtained was for the year 2010 (Table 1). This table specifies the total capacity of plants, their corresponding given size, classifications and efficiencies. For example, the top row states that the total capacity of 1,000 MW plants was 33,000 MW and this constituted 5 per cent of the total capacity in the year. Moreover, such plants are classified as non-SAI units and operate on an average efficiency of 286 g/kWh. Given this information, it can be inferred that the average efficiencies of SAI and non-SAI units in 2010 were 388 g/kWh and 312 g/kWh, respectively.

The capacity composition of newly commissioned coal-fired plants is much harder to obtain. The closest proxy we managed to get was a list of newly commissioned plants published by the National Development and Research Commission (NDRC), see Table 2. In the same fashion as in Table 1, Table 2 lists the total capacity of a group[49] of newly commissioned plants, their corresponding size, technological specifications and efficiencies. By assuming that the entire new fleet put into production in the 12th FYP has the same capacity composition as this sampled group, we infer the average efficiency of the new capacities put into work during the 12th FYP will have an average efficiency of 297 g/kWh. We then further assume that the new capacities put into work during the 13th FYP will have an average efficiency marginally higher[50], which will be 290 g/kWh.

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49 The total planned new capacity in the 12th FYP is 363 Gigawatt (Yearbook). If this is divided evenly into five years, it will be 73 GW per year. The total newly commissioned plants in the list amounts to 20 GW, which is 27 per cent of the total planned per annual.

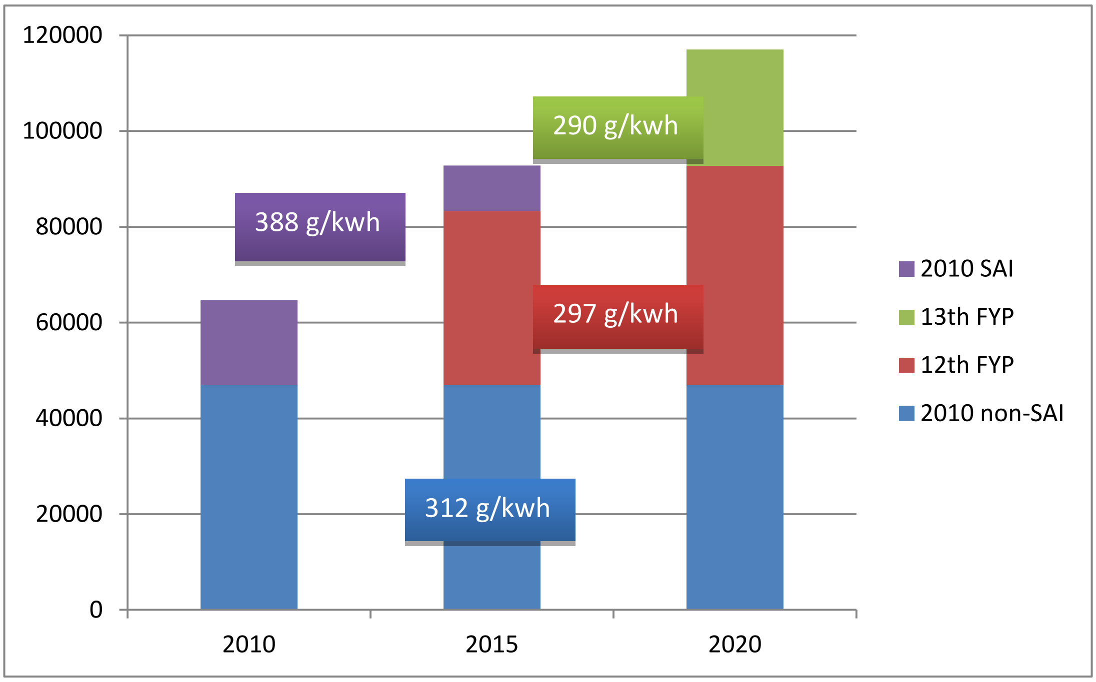
50 Note that a higher efficiency means to use less coal in producing per unit of electricity, hence the g/kwh number will be lower.

Table 2: NDRC commissioned new coal-fired power plants in 2011.

Singles plant capacity (10MW)	Technology	Total capacity 10MW	Capacity share	Efficiency (g/kWh)
100	USC	800	0.4	286
60	USC	240	0.12	292
	SupC	60	0.03	299
	SubC	120	0.06	310
	unknow	120	0.06	299
35	SupC	175	0.09	299
	unknow	70	0.04	310
30	SupC	30	0.02	310
	unknow	330	0.17	310
20	unknow	40	0.02	330
	Weighted average		12th FYP:	**297**
			13th FYP:	**290**

Note: Ultra-supercritical (USC); Supercritical (SupC); Subcritical (SubC).
Source: NDRC (2012), Productivity Commission (2011) .

Figure 4: Total new planned capacity, composition, 10 MW



Source: China Electric Power Yearbook (2012)

The target total capacity of coal-fired power plants by 2015 and 2020 are 928 GW, and 1170 GW, respectively (China Electric Power Yearbook, 2012). We know total 2010 capacity and its composition from Table 1. Combining these and some further assumptions, Figure 4 is obtained. In Figure 4, it is assumed that the non-SAI plants in 2010 will still be serving throughout the policy years at their current efficiency level (312 g/kWh). We also assume all of the SAI plants will be replaced by earmarked plants with similar efficiencies as observed in the NDRC publication (297 g/kWh) – in a linear fashion between 2011 and 2020. It is then further assumed that the average efficiency of new plants that will be built in the 13th FYP that are not earmarked for replacing the 2010 SAI units will 290 g/kWh. Therefore, by assigning efficiency levels to different shares in the total capacity composition in 2015 and 2020, it was possible to conjecture the average efficiency level of the whole coal-fired power generation assets in the two years, namely 314 g/kWh and 302 g/kWh, respectively. These were the efficiencies obtained for the Most-likely scenario.

Table 4 summarises the efficiency scenarios set out in the above analysis. The efficiency levels were ranked from low to high. It turns out that the Scenario 11th FYP trend could lead to the most progressive rate of efficiency improvement. Both Scenario 11th FYP trend and Scenario Post-WTO trend would lead to more efficient power generation than the Scenario Cutting-edge would. This suggests it is unlikely that efficiency is going to improve over the next 10 years as fast as it did over the past 10 years. On the other hand, Scenario Most-likely and Scenario 12th FYP target both would lead to lower efficiencies than Scenario Cutting. This suggests these Scenarios might be more realistic. Nevertheless, these scenarios indicate a range in which the rate of efficiency improvement might evolve in the policy years.

Table 4: Efficiency scenarios

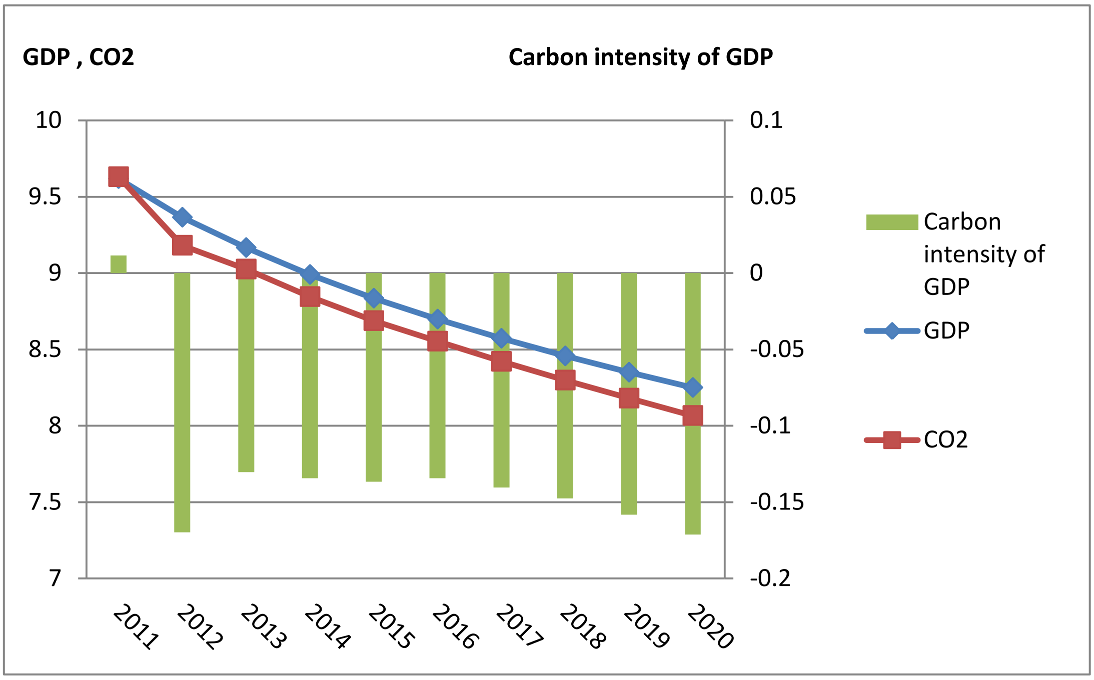
Scenario	2011 (g/kWh)	12-15 p.a. Gr_R (%)	2015 (g/kWh)	16-20 p.a. Gr_R (%)	2020 (g/kWh)
Constant	330	*0*	330	*0*	330
12th FYP target	330	*-0.38*	325	*-0.62*	315
Most-likely	330	*-1.23*	314	*-0.78*	302
Cutting-edge	330	*-0.77*	320	*-2.09*	288
Post-WTO trend	330	*-1.73*	308	*-1.73*	282
11th FYP trend	330	*-2.08*	303	*-2.08*	273

Source: Authors' calculation

3. The back of the envelope (BTE) model

These scenarios were put into a simple back of the envelope (BTE) model. The BTE model adopts a baseline (Figure 5) that is the same as the one used in the CGE model (see Section 4). Thus, the two simulation results are comparable. This baseline is derived from the Monash-style CGE model we used, CHINAGEM, a documentation of which can be found in Mai et al., (2012).

Figure 5: Baseline year on year percentage change in GDP, CO2 emissions and carbon intensity of GDP, over the policy years



Source: CHINAGEM

Since carbon intensity is defined as CO2 emissions over GDP, see Equation 1[51]:

$$INTENSITY_t = \frac{CO2_t}{GDP_t}. \quad [E1]$$

Total differentiate E1 gives Equation 2:

$$intensity_t = co2_t - gdp_t, \quad [E2]$$

where lower case *intensity*, *co2* and *gdp* represent percentage change in upper case variables *INTENSITY*, *CO2* and *GDP*, respectively. This BTE analysis assumes that changes in coal-fired power plants efficiency do not change GDP, thus all efficiency scenarios have the same percentage changes in GDP, which is the baseline percentage GDP changes as shown in Figure 5.

51 Following a tradition in Monash-styled notation, we denote quantity changes in upper-case letters and percentage changes in lower case letters.

The derivation of percentage change in CO2 emissions, as defined in Equation 3, is also straightforward.

$$co2_t = \frac{CO2_t - CO2_{t-1}}{CO2_{t-1}} * 100$$

[E3]

In CHINAGEM database, the total carbon dioxide emissions in 2010 ($CO2_{2010}$) are 8081 million tonnes. Thus $co2_{t+1}$ can be derived by finding $CO2_{t+1}$, from Equation 4:

$$CO2_t = CO2_{t-1} + \Delta CO2_{t-1}$$

[E4]

Which in turn can be derived by finding the changes in CO2 in time t ($\Delta CO2_t$), from Equation 5:

$$\Delta CO2_t = \partial * \Delta COAL_t$$

[E5]

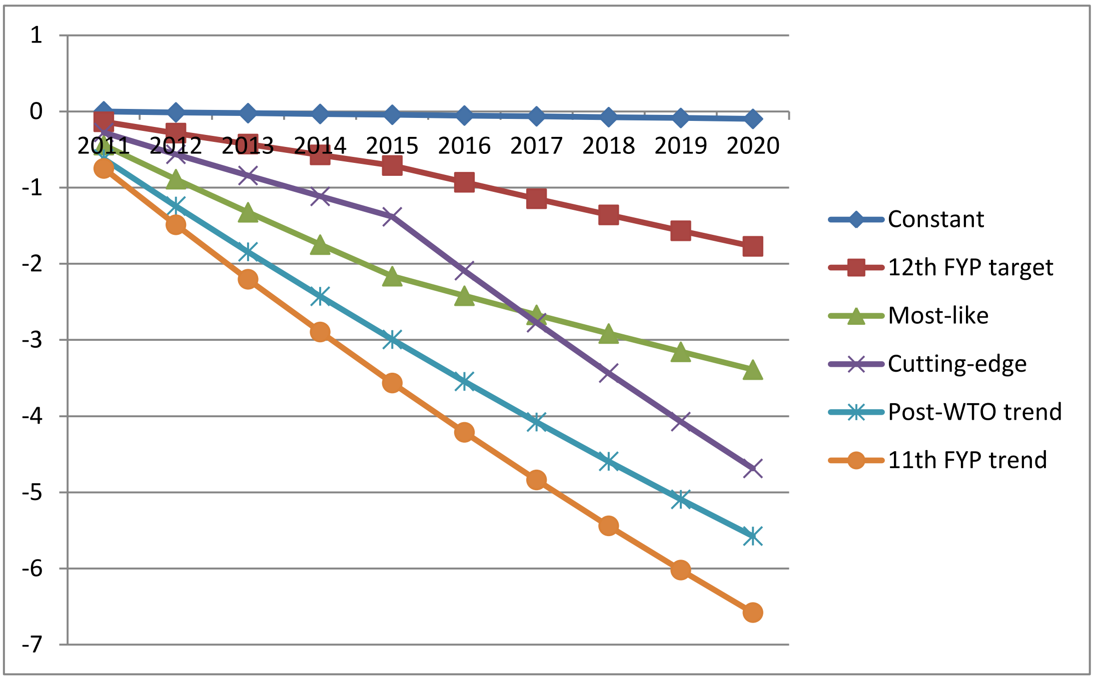
Where ∂ =2.47 is a fixed coefficient and $\Delta Coal_t$ represents the change in total consumption of standard coal in time t, which in turn can be derived from Equation 6:

$$\Delta COAL_t = \Delta A_t * COALELEC_t \quad \text{[E6]}$$

Where ΔA_t is the change in the efficiency of coal-fired power generation plants (g/kWh). This is where the different efficiency scenarios (as shown in Table 4) come in. And $COALELEC_t$ is the quantity of power-fired electricity projected to be used in year t. Again, we use the quantity[52] of coal-fired electricity projected to be used in year t from the CHINAGEM baseline. By this it is assumed that the change in power-generation efficiency will not change the quantity of electricity consumed (another unsatisfactory assumption due to the limitation of partial equilibrium analysis). Solving the equation system E2 – E6, with five equations and five unknowns ($intensity_t$, $co2_t$, $CO2_t$, $\Delta CO2_{t-1}$ and $\Delta COAL_t$), we were able to obtain $intensity_t$ in each of the efficiency scenarios (see Figure 6).

[52] A CGE database is in value. Here the value of coal-fired electricity output in 2010 is divided by external quantity data (3216 TWh) from the China Electric Power Yearbook 2011. This results in an average coal-fired electricity on-grid price of 0.25 yuan per kWh, which, in the absence of data, is believed to be plausible. Thus, we assume the quantity of coal-fired electricity generation in 2010 is 3216 TWh in the database.

Figure 6: Cumulative percentage deviation in carbon intensity of GDP from baseline under different efficiency scenarios, BTE simulation



Source: Authors' calculation

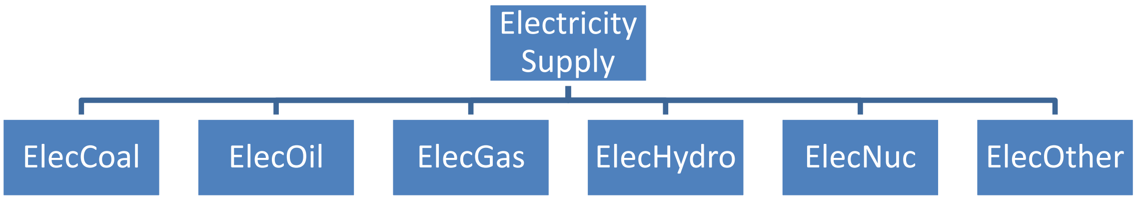
Figure 6 shows that even under the most progressive efficiency improvement scenario (11th FYP trend), coal-fired power plant efficiency improvement will not contribute to more than 7 per cent of total carbon intensity reduction from 2010 to 2020. Compared with the targets of 32.6 to 38.2 per cent, the 11th FYP scenario (6.58 per cent) will contribute only 17 to 20 per cent of the total reduction in carbon intensity. Moreover, under the Most-likely scenario, the cumulative contribution by 2020 will only be 3.4 per cent, which is 8.9 to 10.4 per cent of the total carbon intensity reduction. Hence these BTE results show that coal-fired power generation efficiency improvement over the policy years may not play a defining role in delivering the intensity targets by 2020.

4. General equilibrium analysis

(i) General equilibrium results

In this section the efficiency scenarios developed in Sector 2 and applied in Section 3 is put into a CGE model. The CGE simulations are based on the following key assumptions in the general equilibrium simulation. First, the coal-fired power sector (ElecCoal in Figure 7) is one of the electricity generation sectors that only sell to the Electricity Supply sector. The elasticity of substitution among the generation sectors is set to be 0. In the absence of trusted elasticity data, the CGE results are delineated from dubious fuel substitution effects. This is nevertheless a reasonable assumption since it is found in the literature that fuel substitution has had little impact on carbon intensity in China (Ma and Stern (2008)). Second, it is assumed that both nominal private consumption and nominal public consumption to be a fixed proportion of nominal gross national product (GNP). Third, we let investment to be a positive function of real capital return (see Dixon and Rimmer, (2007)).

Figure 7: Electricity production structure



Moreover, factor market assumptions are distinguished between short-run and long-run. It is assumed in the short-run (year of shock) that real wages are sticky and employment can deviate from the baseline to accommodate the shock created by the shock. Capital employment on the other hand is fixed, thus a shock can cause real capital return to deviate from baseline. In the long-run however, we assume real wage can change over time and the level of employment tends to approach its long-run level (the baseline level). Capital employment, on the other hand, could vary in the long-run, but real return to capital tends to approach its baseline levels. These factor market assumptions are summarized in Table 5:

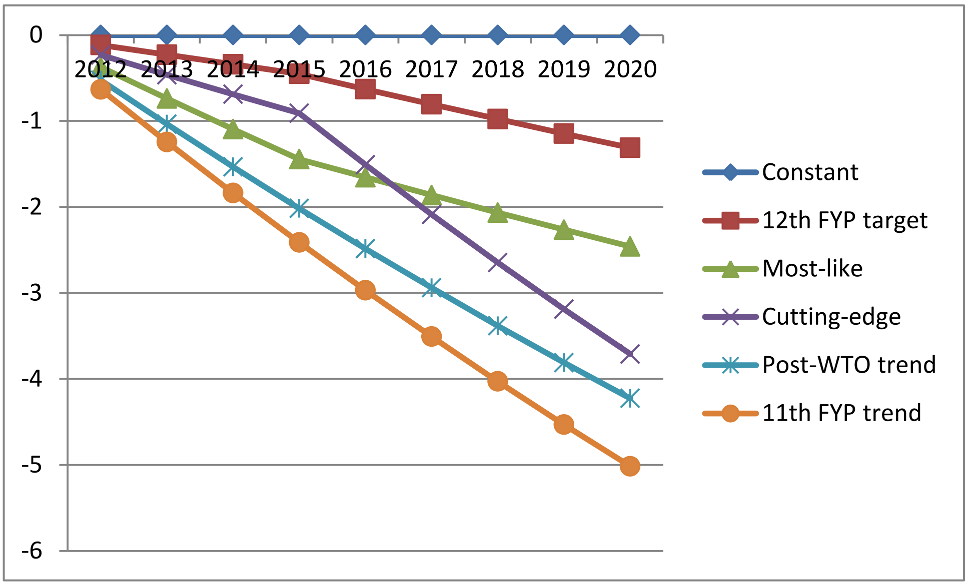
Table 5: Factor market assumptions

Factor market		Short-run (2012)	Long-run
Labour market	Real wage	Sticky	Deviate from baseline
	Employment	Deviate from baseline	Approach baseline
Capital market	Real return	Deviate from baseline	Approach baseline
	Capital	Fixed	Deviate from baseline

Figure 8 shows the efficiency impacts on carbon intensity of GDP obtained from CGE simulations. In comparison with Figure 6, Figure 8 shows yet smaller contributions to carbon intensity reductions. This is due to the rebound effect. An efficiency increase reduces the cost of producing coal-fired electricity which in turn electricity retail price. Electricity users thus benefit from the lower electricity price. Consumers increase their consumption and industries increase their electricity input and expand their activity levels. These second-order changes lead to a slightly higher demand for electricity that is not captured in our BTE analysis.

The higher demand in electricity on the one hand leads to smaller reductions in carbon emissions and on the other hand leads to higher GDP levels. Overall, the rebound in carbon emissions is larger than the increase in GDP. This is because the increase in GDP is driven by higher electricity demand, so the rebound in GDP is secondary to the rebound in electricity demand and is thus smaller than the rebound in carbon emissions.

Figure 8: Cumulative percentage deviation in carbon intensity of GDP from baseline under different efficiency scenarios, general equilibrium simulation



Source: CHINAGEM simulation results

(ii) An investment and taxation package to improve efficiency

The efficiency improvement cannot be treated as a gift from ‘heaven’, it has to be financed. It is assumed that the government invests in the coal-fired power generation industry to achieve efficiency improvements, and it finances the investment by imposing a production tax on the industry. This section focuses on the Most-like scenario as it is the only scenario for which data is available. The industry-level impacts on the economy under this scenario are observed. The impacts of other efficiency scenarios should follow the same pattern as it is observed in the Most-likely scenario.

Inevitably, it is necessary to estimate the amount of investment needed to achieve the efficiency improvement. The amount of investment needed is estimated by using what is called the ‘premium investment’ measure. Table 6 illustrates how the premium investment is measured. First, it is known from the NDRC website how new capacities were commissioned in 2011 and their respective plant type. Second, it is known how much investment is needed to build a certain type of coal-fired power plant from the Productivity Commission study (2011). The per unit investment required for building subcritical plants is the base, and this base is subtracted from the unit investment required for building more advanced plants, namely supercritical and ultra-supercritical plants. The differences, after subtracting the basis, is known as the 'technological premium', which estimates the extra unit investment required for investing in more efficient plants. Then the technology premium is multiplied by their respective commissioned capacities to get the premium investment. The premium investment[53] thus estimates the amount of investment accountable for efficiency improvement that is needed for the NDRC commissioned projects in 2011 (RMB 10020 million).

Moreover, it is also known from the China Electric Power Yearbook what the planned total of new capacity is to be built over the 12th and 13th FYP years. By assuming a linear capacity expansion pace, it is possible to estimate how much new capacities is needed per annual. By dividing the total capacities commissioned by the NDRC in 2011 by the annual capacity expansion, the NDRC commissioned capacities in 2011 as shares of planned annual capacity expansion is obtained over the 12th and 13th FYP periods (23 and 29 per cent, respectively). By then scaling the 2011 investment up according to these shares, it is possible to estimate the annual premium investments needed during the 12th and 13th FYP periods (RMB 42,819 and RMB 34,008 million, respectively). Accordingly, the amount of the production tax collected is be the same as the amount of investment.

Table 6. Estimating premium investment

Plant Type	**NDRC capacity[1] (10MW)**	**Cost[2] (RMB 10 million /10MW)**	**Technology premium (RMB 10 million/10MW)**	**Premium Investment (RMB 10 million)**
SubC	560	4.06	0	0
SupC	385	4.54	0.475	182.875
USC	1040	4.85	0.788	819.52
sum capacity	1985		sum inv	**1002**
		Capacity p.a.	NDRC shr	inv p.a.
Total 12th FYP new	42396	8479	23%	**4281.9**
Total 13th FYP new	33673	6735	29%	**3400.8**

[53] This may marginally underestimate the total investment needed for efficiency improvement since a small margin in investment for building subcritical plants may also contribute to efficiency improvement.

Source: NDRC (2012), China Electric Power Yearbook (2012), Australia Productivity Commission (2011), authors' calculation

These estimations are applied into the four scenarios. Scenario Efficiency simulates the original efficiency improvement under the Most-likely scenario without investment or tax. Scenario Investment and Scenario Taxation each simulates the investment and taxation, individually. Scenario Overall simulates the efficiency improvement, the investment and the taxation together. By comparing these four scenarios, it is possible to observe the contribution from each policy component as well as the overall policy impact.

(iii) Financing the efficiency improvement – macro level analysis

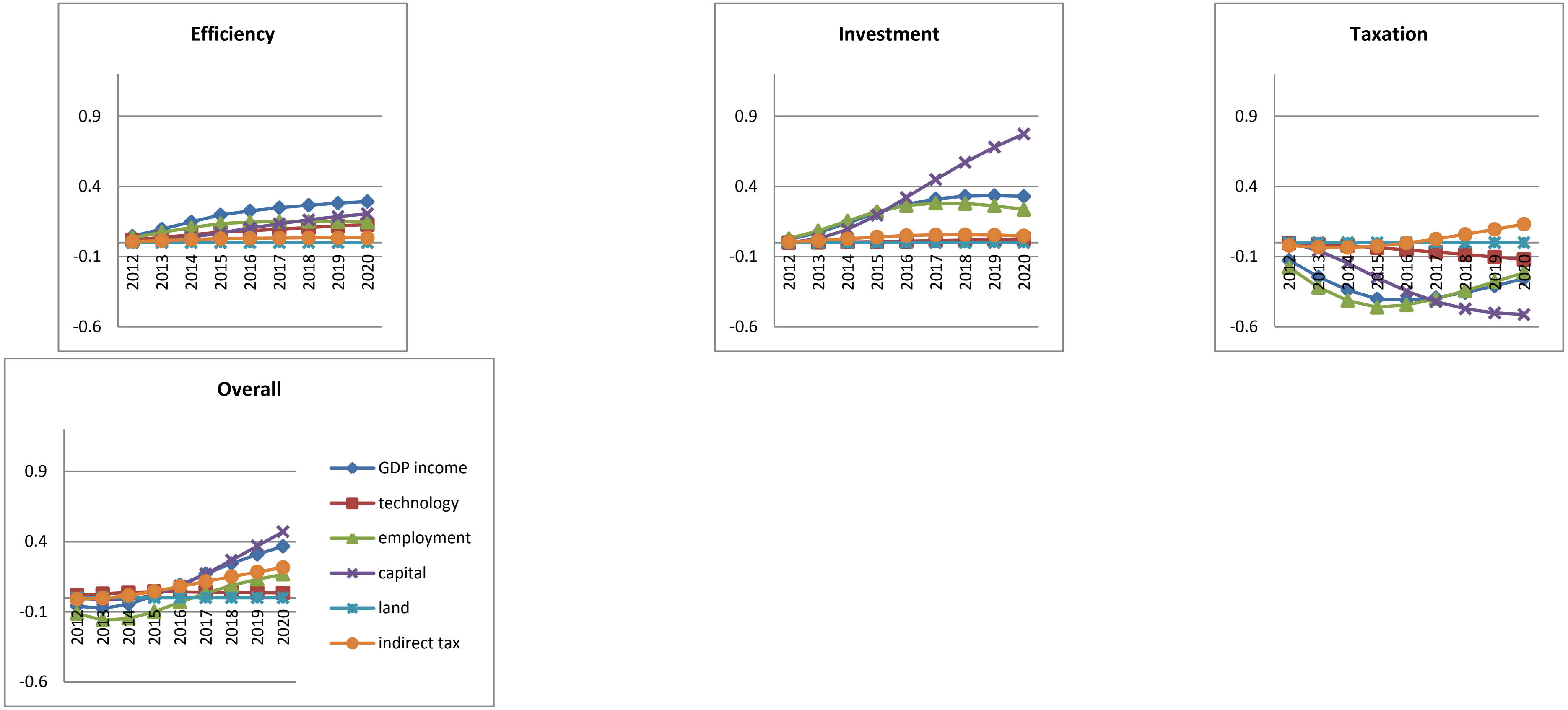
Set 1 shows the simulation results from the income side of GDP for the four scenarios. Despite the initial fall in GDP, which is due to a fall in labour employment, by 2020 the overall impact of the policy package will be positive on all the income-side components of GDP[54]. The initial fall in labour employment originates from the taxation scenario. Referring to Table 5, every year when more indirect tax is imposed, real wage is sticky in reacting to the incremental tax but the real return to capital can adjust quickly, thus producers will face a relatively higher labour cost than capital cost on the margin. While capital employment is slow in reacting to the incremental tax, employers will employ less labour in response to the relatively higher marginal labour cost, thus reducing labour employment.

In the long-run however, wages starts to accommodate the fall in labour demand and this allows labour employment to approach the baseline. On the other hand, capital return approaches the baseline from above, leading to a fall in capital employment. Despite the fall in capital employment originating from the taxation scenario, among all the income-side components, capital will experience a higher growth. This mostly derives from the Scenario Investment in which the positive investment shock stimulates capital demand overtime.

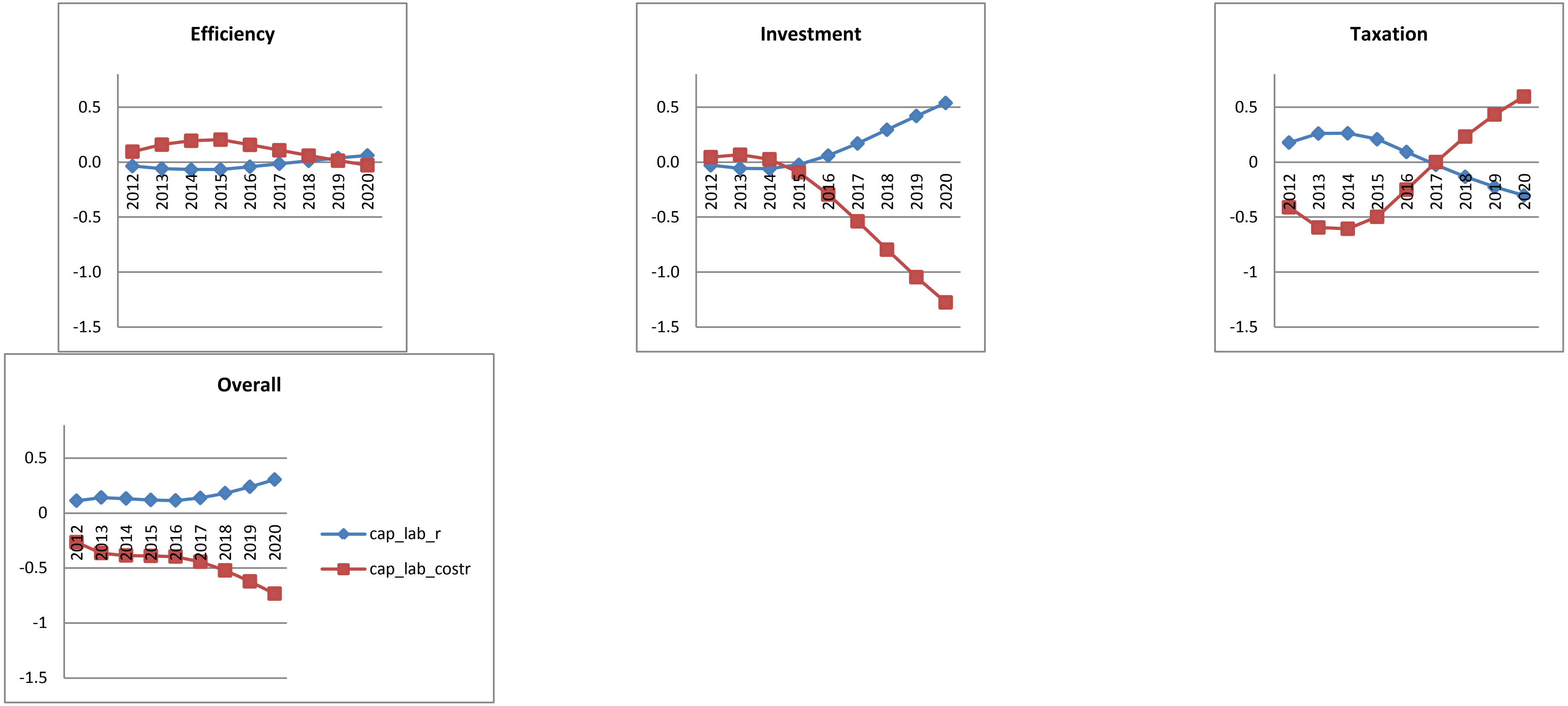
Set 2 plots the relative changes in capital to labour employment ratio (cap_lab_r) and in capital to labour marginal cost ratio (cap_lab_costr). It shows that while the efficiency scenario is relatively neutral, the investment scenario is more capital-enhancing whereas the taxation scenario is more labour-enhancing. Overall, as capital becomes relatively cheaper than labour in the long-run, more capital will be employed than labour. This is good news to capital intensive industries and bad for labour intensive industries, a point examined later in the industry analysis (Section 4.3).

[54] Except for changes in land is zero, which is specified by consumption.

Set 1, GDP from income side, cummulative percentage deviation from baseline



Set 2, relative change in capital labour employment and marginal cost ratios, cummulative percentage deviation from baseline

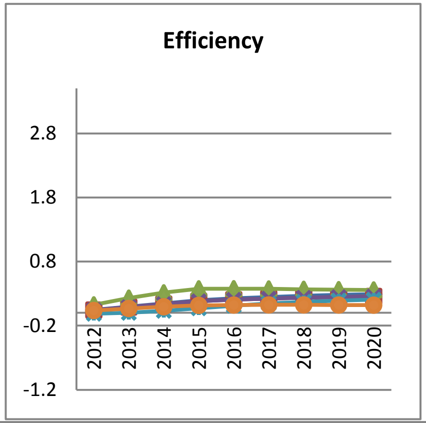


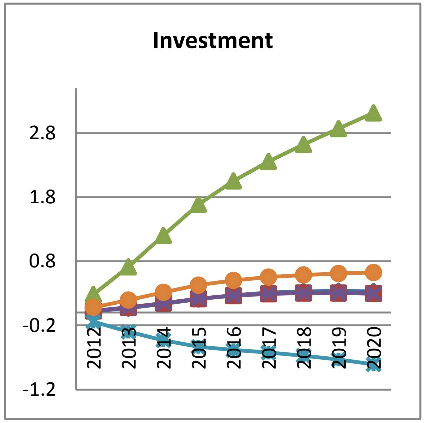
The expenditure side of GDP: Set 3 shows simulation results from the expenditure side of GDP for the four scenarios. The overall scenario shows that apart from export, all components from the expenditure side of GDP increase, with investment increasing the most. This is primarily driven by the increase in investment which originates from Scenario Investment. The increase in investment in this scenario is again partially offset by the fall in investment which originates from Scenario Taxation in the early years of the simulation. This fall in investment is due to the decline in capital return. Recall from Section (i) that investment is a positive function of real return to capital, and that the decline in capital return will lead to a decline in investment. But this second-order decline is not enough to offset the first-order shock that increase the investment in the coal-fired power generation sector.

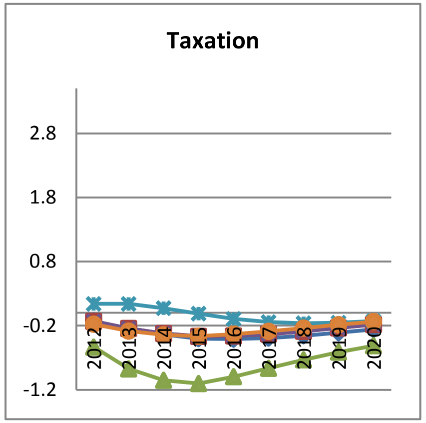
Set 4 explores the dynamisms in the trade sector. The simulation shows import will increase while export will fall, accompanied by an increase in terms of trade and a real RMB appreciation. Again, the most significant changes originate from the increase in investment. The increase in investment is a demand side shock, in a general equilibrium setup that is constrained by the given levels of production factors and technology, the increase in investment does not impact on supply side variables as large as the increase in itself. Hence, to maintain equal changes from both supply and demand sides of GDP, other components in the demand side of GDP will fall to accommodate the big investment increase.

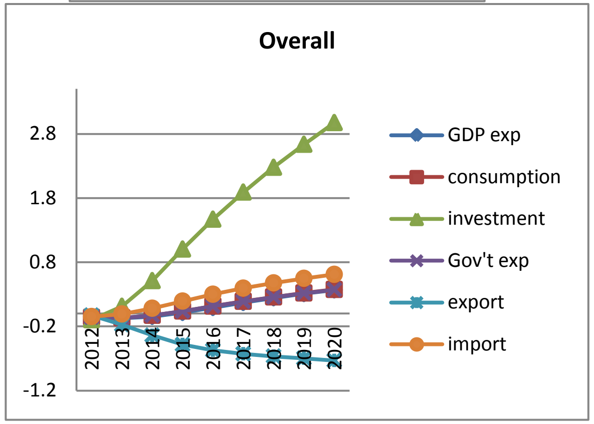
Given that private and government consumption follows national income, net export needs to fall. Import on the one hand will increase in response to the higher domestic demand due to higher investment. But on the other hand the increase in import will be smaller than the increase in investment, since not all the incremental investment is imported, thus export also fall in order to facilitate a fall in net export that is comparable to the increase in investment. Given a relatively stable import price and a downward sloping export demand curve, the fall in export increases export price and increases terms of trade. Moreover, the lower net export signals a reduction in the country’s competitiveness, which is accommodated by a real RMB appreciation. Such dynamisms in the trade sector are negative signals to both export-oriented and import-competing sectors.

Set 3, GDP from expenditure side, cummulative percentage deviation from baseline

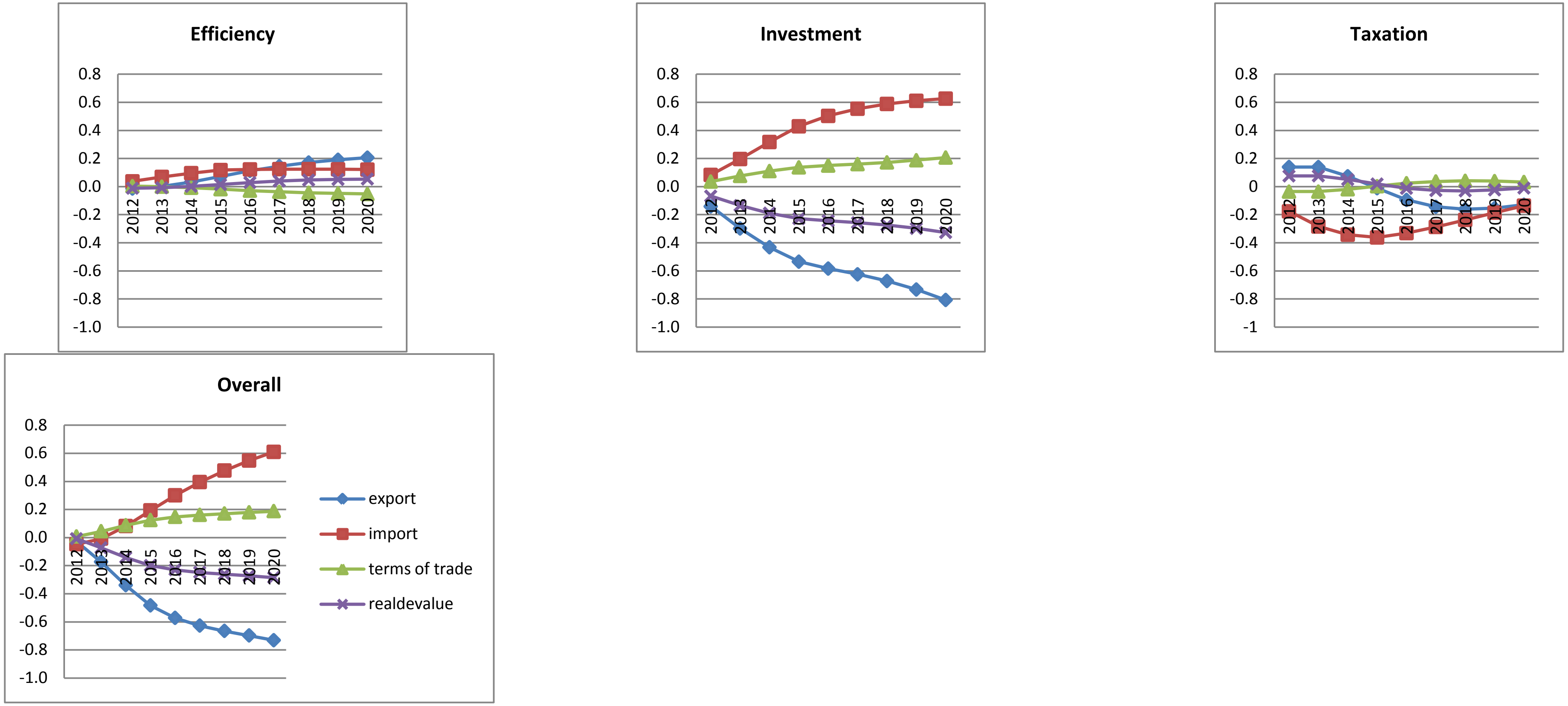




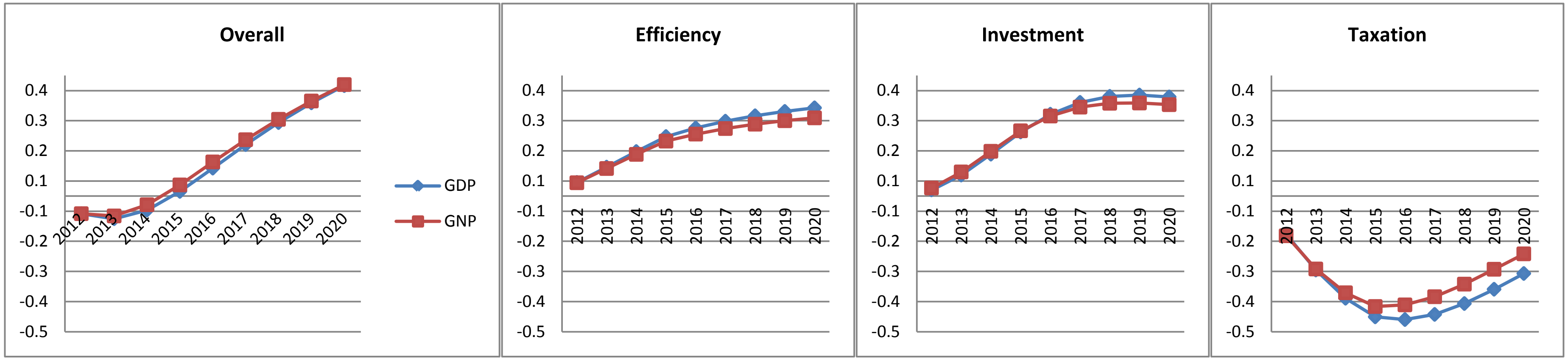




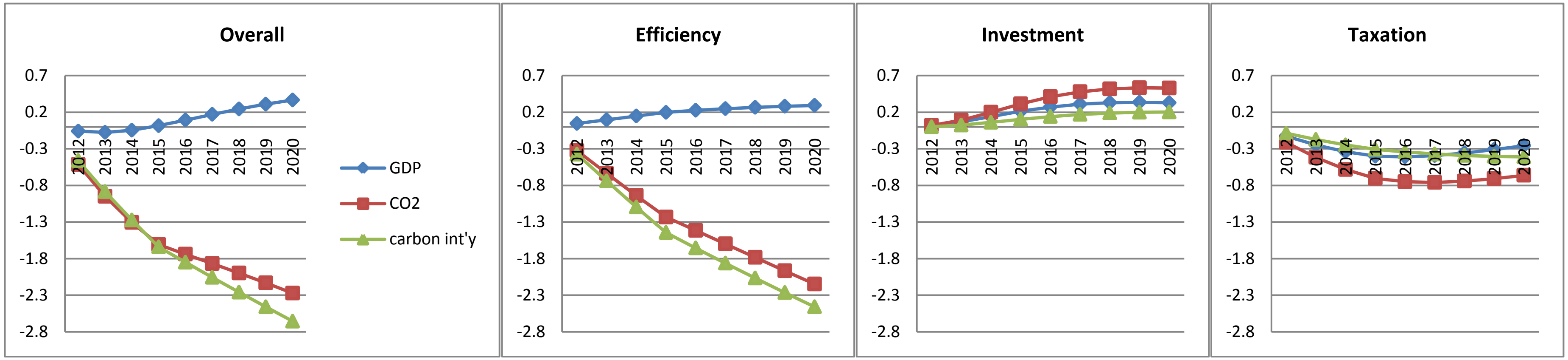
Set 4, trade and trade-related prices, cummulative percentage deviation from baseline



Set 5 GDP and GNP, cumulative percentage deviation from baseline



Set 6, GDP, CO2 and carbon intensity of GDP, cumulative percentage deviation from baseline



GNP, which more correctly measures a country's welfare, can be different form GDP. Set 5 illustrates the difference between the two, or the indifference as it is shown in Scenario Overall. Under Scenario Efficiency and Investment, GDP is slightly higher than GNP, since under these scenarios investing in China yields higher return in the short-run, and as net-international lending reduces GNP becomes slightly smaller than GDP. The opposite mechanism operates in Scenario Taxation. The overall difference between GDP and GNP is negligible.

Set 6 shows changes in GDP, CO2 emissions and carbon intensity of GDP. Comparing Scenario Overall and Efficiency, the difference between with and without the policy package (investment and taxation) is very small. However, all the small differences act in the more favourable direction: GDP is slightly higher and CO2 emissions and carbon intensity are slightly slower.

(iv) Financing the efficiency improvement – industry level analysis

Industry-level results are consistent with macro-level results. Sets 7, 8, 9 and 10 each shows the ten most positively affected and the ten most negatively affected industries under Scenarios Efficiency, Investment, Taxation and Overall, respectively.

When only the efficiency improvement is considered, all income and expenditure components of GDP are affected roughly the same (with small increases). Hence the industries that are most directly involved with the efficiency improvement will gain the most. As it is shown in the left panel of Set 7, these are the electricity generation industries. They benefit from the lower cost of producing electricity and an economy-wide higher demand for electricity. Although the industries of Basic Chemical (BasicChem) and Salt Mining (SaltMine) stand out as the most positively affected, which seems unreasonable. However the fact that the Basic Chemical industry uses up the largest share of electricity output explains the results, since it gains the most from the fall in electricity price. The Salt Mining industry on the other hand simple benefits from selling most of its outputs to the Basic Chemical industry.

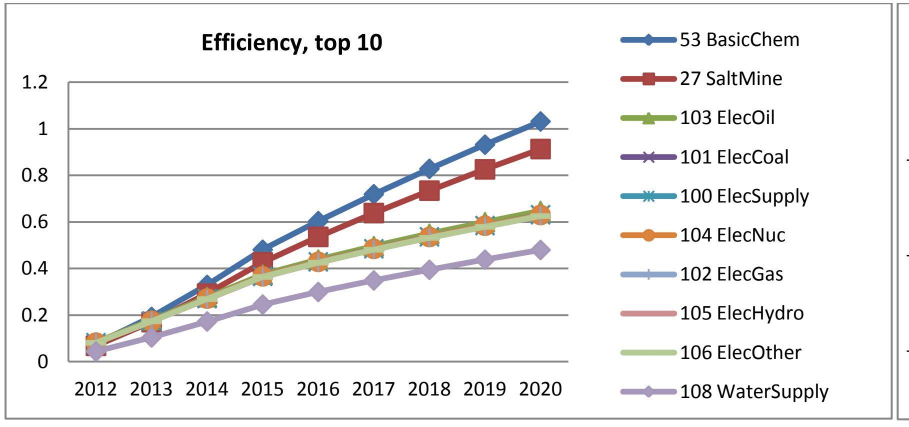
The industry that is most adversely affected is the industry of Coal and Mining Products (CoalMineProc), shown in the right panel of Set 7. This is due to the efficiency gain that requires less coal as an input to coal-fired electricity generation. The industry of Railway Freight (RealFreight) is found to be the second most adversely affect. This is because a large share of the industry's activities involves the transportation of coal.

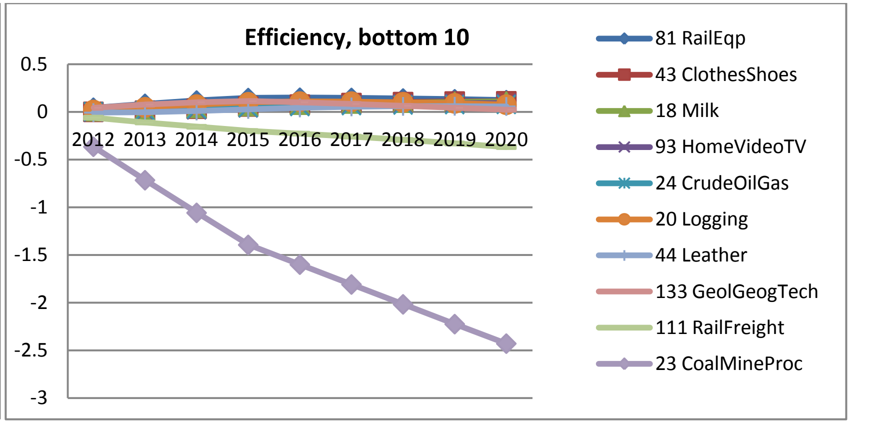
Scenario Investment shows a different pattern from Scenario Efficiency. From the macro-level results, it is observed from the expenditure side of GDP that investment increases more in relation to the other components whereas exports fall more. On the income side it is observed that the capital labour ratio increases over time. This suggests capital intensive industries are likely to gain more than the labour intensive industries. Again, industry level results are consistent with the macro-level results. On the left panel of Set 8, industries such as Construction and Cement benefit the most from the positive investment shock. This is because they both sell a large share of their outputs as investment goods as well as being relatively capital-intensive in the production process. On the right panel of Set 8 however, industries that are trade exposed and are relatively more labour intensive such as Textile Products (TextProc) are found to the most adversely affected.

Scenario Taxation has yet a different combination of winners and losers. Since the tax does not create much difference on the expenditure side of GDP, changes from the income side of the GDP dictate the industry-level results. Given that by 2020 more capital will be employed than labour – compared with the baseline – labour intensity industries are likely to gain more than the capital intensive industries. As it is shown in the left Panel of Set 9, Leather, Knit Mill and other traditional labour-intensive industries are least affected by the tax. On the other hand, the tax increases the cost of electricity generation, increases electricity price, and thus reduces electricity output and those industries that use a large share of electricity output.

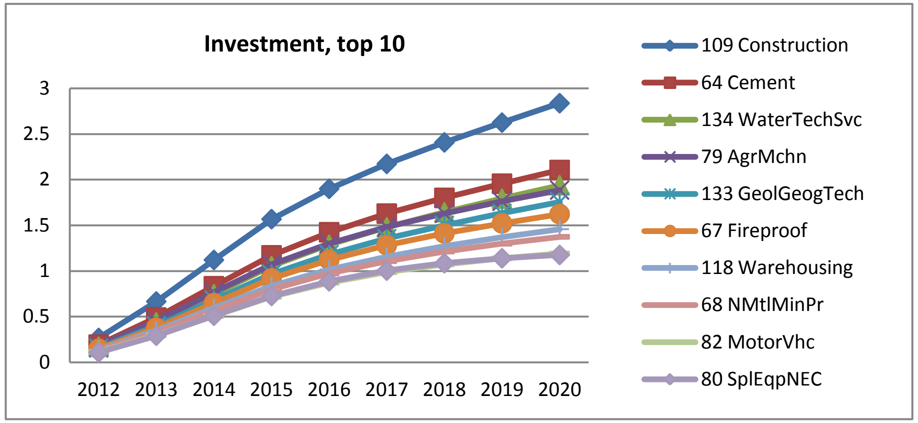
The overall impact of the policy package on industries are such that 1) the increase in investment is a strong demand side stimulus that alleviates industries that specialise in selling investment goods – especially those who are also relatively capital-intensive. 2) the higher investment however crowds out export and increases imports, thus hurting the trade-exposed industries – especially those who are also relatively labour-intensive. 3) The Coal Mining industries will be mostly hurt due to the adoption of more coal-saving technologies. 4) The production tax has a big negative effect on the electricity generation industries that neither the improvement in efficiency nor the increase in investment could lead to an overall positive impact to these industries. This is characterised by the results that the Basic Chemical industry becomes one of the biggest net losers overall. The result of the Basic Chemical industry losing indicates higher overall electricity price and lower overall electricity output. This last result is interesting because it is in contrast to the thinking that higher efficiency in the power sector should lead to higher output at lower prices. It also explains why total carbon emission in the Overall scenario is slightly lower than it in the Efficiency scenario.

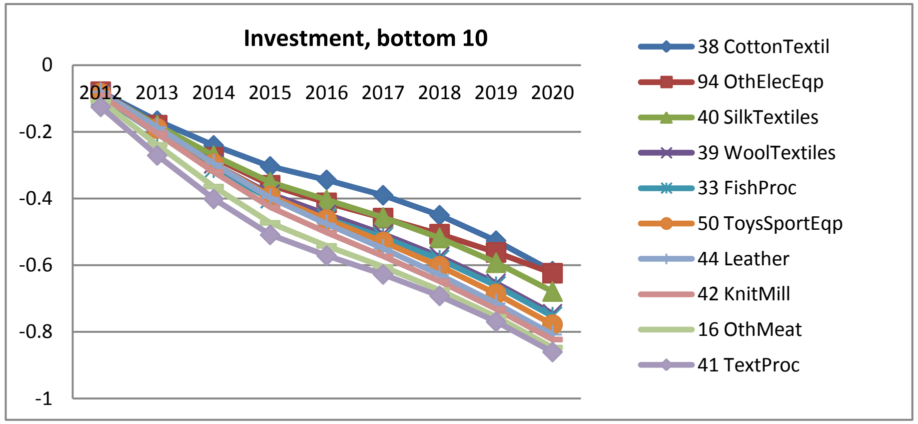
Set 7, Scenario Effciency, cumulative percentage deviation in industry-activity level from baseline, top and bottom ten



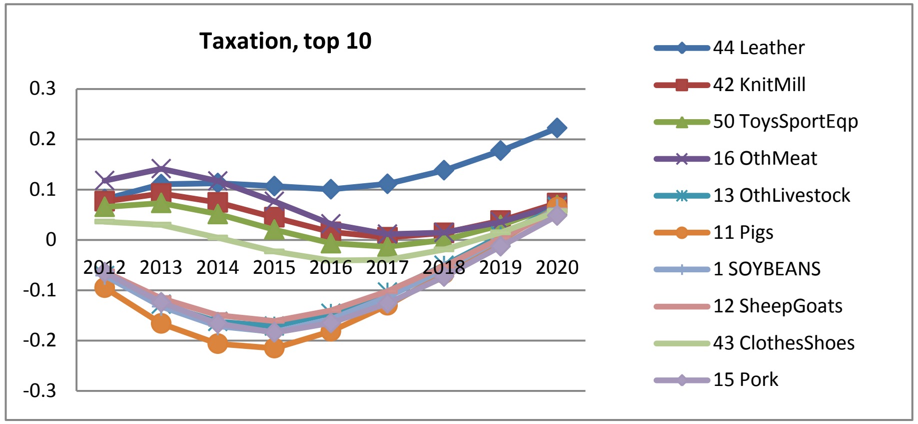


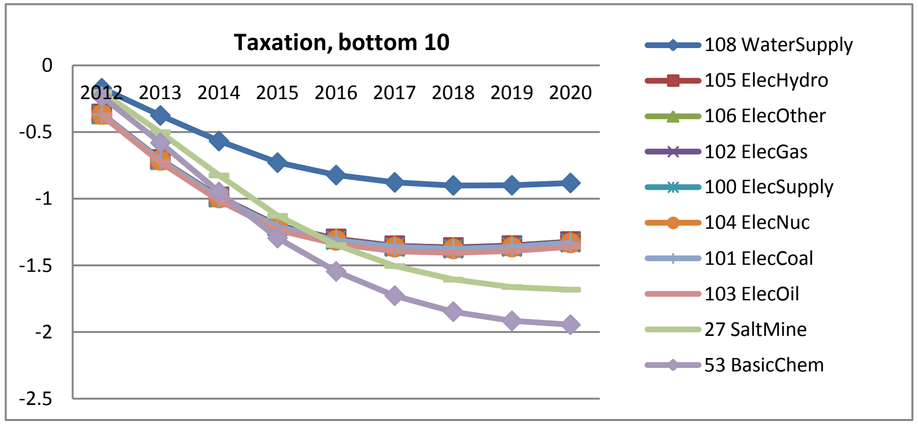
Set 8, Scenario Investment, cumulative percentage deviation in industry-activity level from baseline, top and bottom 10



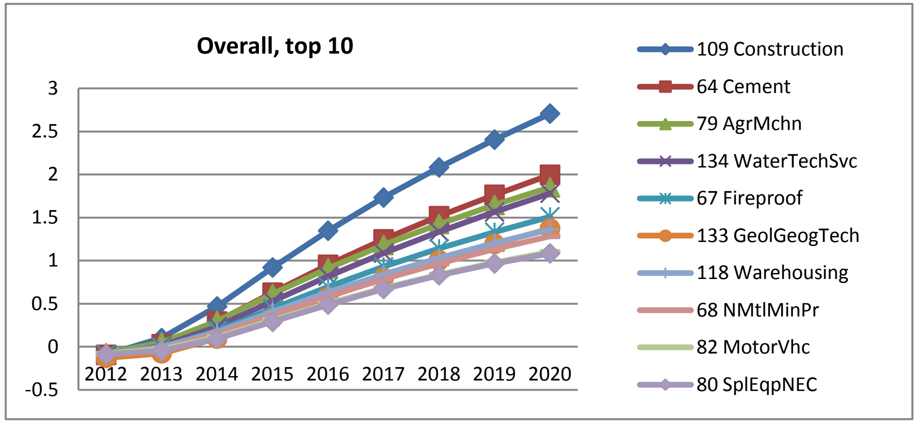


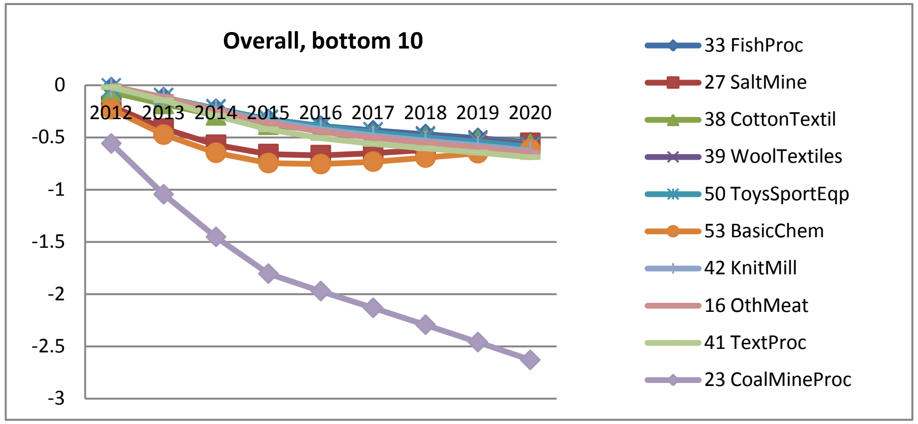
Set 9, Scenario Taxation, cumulative percentage deviation in industry-activity level from baseline, top and bottom 10





Set 10, Scenario Overall, cumulative percentage deviation in industry-activity level from baseline, top and bottom 10





5. Conclusion

The simulation results shows that investment in improving coal using efficiency in coal fired electricity generation leads to a faster growth in real GDP due to the productivity improvement and resultant faster growth in capital employed in current production. Despite this rebound effect, the investment in the efficiency improvement still leads to an overall reduction in CO2 emission, resulting in an overall reduction in emission to GDP ratio.

The efficiency scenarios in Section 2 show that given the current predictions of technological advancement it is unlikely that China's coal-fired power plants are going to enjoy the same rate of efficiency improvement in the coming ten years as they did over the past ten years. This is partly because China was able to phase out small and inefficient old power plants in the past, and such opportunities are shrinking. It is also partly due to China's new power plants quickly approaching the technological frontier in the world. However, our assumption here is that China is not going to be expanding to the world technological frontier in the coming ten years.

From our simple back of the envelope calculation we find that efficiency improvement in the coal-fired power generation sector is unlikely to bring major reductions in China's carbon intensity of GDP – even if the rate of efficiency improvement can be as high as it was during the 11th FYP period. This suggests there should be other factors (e.g. renewable energy development and carbon pricing) that are strong enough to help China achieve its intensity-based targets.

The CGE simulation further emphasises this point by showing that the rebound effect is going to lead to even smaller contribution to carbon intensity reduction from more efficient power generation. Our simulation also shows when the efficiency improvement is made possible through higher investment which in turn is financed by higher tax, it could lead to slightly more reduction in carbon intensity, although such a reduction is still smaller than the reduction obtained from the BTE analysis. It is important to notice that this slightly greater reduction in carbon intensity is achieved by lower carbon emissions and higher GDP, and that both are positive results on their own. Taking into consideration investment and tax, the impact of efficiency improvement on GNP is almost identical to the impact on GDP. This is slightly different from the scenario in which only the efficiency improvement is considered, where GNP is slightly lower than GDP. But the difference is very small.

The industry level results are consistent with macro level results. When the financing package is considered, we find investment has the strongest impact in driving industries to expand, hence industries that have large outputs sold as investment goods are set to gain the most. Further, input-output linkage, trade-exposure, and relative capital to labour ratio in production technology all play some part in determining the results. However the most interesting industry level result is that electricity generation industries are not expected to expand as much as when only efficiency improvements are considered, because of the tax bestowed on the industry.

As a further note, the financing package is by itself an interesting exercise since it is replicable when the financing tool is used for other purposes, such as investing in renewable energy. The impact of investment and taxation should have similar patterns regardless of how the money raised is spent. However the amount of the tax collected may be different in every case.

There are also many aspects where our study could be improved. The study would benefit by an extension to a longer time span, for example to 2030. Then observations can be made about the impact to the economy, as the lagged policy effects begin to dominate after the shocks are all employed by 2020. Second, the efficiency scenarios are very simplistic; further integration of our model with more advanced models from outside the economics discipline would produce more interesting results. Moreover it also has to be noted that the pricing mechanism in China’s electricity market is not fully market-oriented, and therefore further effort is needed to study the impact of liberalising China’s energy market.

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