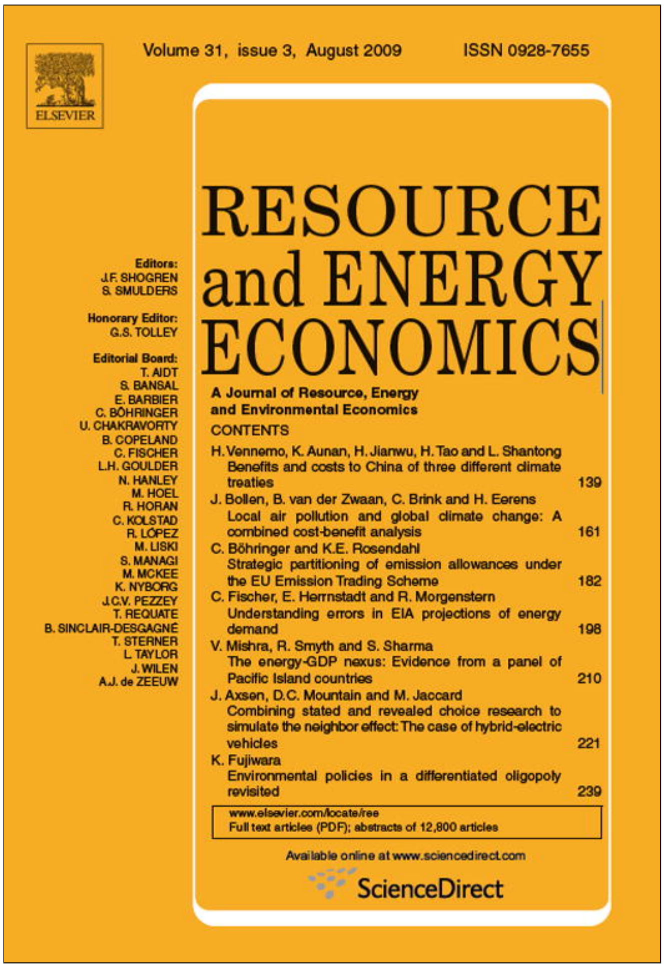
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Benefits and costs to China of three different climate treaties

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ABSTRACT

There are currently several ideas on the table for a climate treaty post-Kyoto. We consider the impact on China of three ideas: a cap on the CO_2 intensity, a cap on the CO_2 level, and a cap on the CO_2 intensity in key sectors. We find that a cap on the CO_2 intensity gives large environmental co-benefits to China on aggregate, but there are significant negative effects for rural households. Assuming these are addressed the country could reduce its CO_2 intensity by a third before costs outweigh environmental co-benefits. By contrast a cap confined to the manufacturing and power sector does not bring substantial co-benefits to China.

1. Introduction

An essential issue in future climate treaties is how to bring developing countries on board. 38 countries have ratified the Kyoto Protocol and committed to greenhouse gas emission reductions. But these countries cover less than a third of global CO_2-emissions (IEA, 2007) and the share is falling over

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time. Hence a future treaty must emphasize emission reductions in the rest of the world including developing countries.

Developing countries find it difficult to commit to an emission reduction since it might interfere with the much-needed development of their economies. Besides, greenhouse gas emissions in developing countries are low on a per capita basis. China, for instance, is probably the largest source of CO_2-emissions in the world (MNP, 2007), but CO_2-emissions per capita are only no. 73 (WRI, 2008). The moral case for prioritizing emission cuts in country no. 73 is weak.

The right of developing countries to develop on the one hand, and on the other hand the need for a future climate treaty to include as many developing countries as possible, make it important to know the impact of alternative treaty designs on developing countries. Here we discuss the costs and benefits to China of alternative treaty designs. Because of its size and position as the largest source of CO_2-emissions in the world, China is an important representative of developing countries.

By illuminating the costs and benefits to China of different treaty designs we are not claiming that the country is on the verge of joining any of them. Although China is taking tentative steps to formulate an active climate policy, e.g., NDRC (2007), the policy discussion in China has a focus on sulfur reductions and energy efficiency rather than explicit CO_2 commitments. What we are claiming is that knowing the costs and benefits of different treaty designs is relevant background for policy discussions both in China and internationally.

In this context it may be asked what the benefits to China of joining a climate treaty really are? We focus on environmental co-benefits, in the form of local air quality improvements that improve public health and improve yields in Chinese agriculture. These are benefits that previous research has indicated to be large (e.g., World Bank, 1997, 2007; Aunan et al., 2004, 2007; Ho and Jorgenson, 2007).

Of course, China may obtain environmental benefits without the detour of a climate treaty. But air pollution policy is uneven and weak in China. Given the situation that is, the question we ask is whether interventions to reduce CO_2-emissions offer the potential of killing two birds with one stone.[1] One could equally well have asked the opposite question of what is the co-benefit in terms of CO_2-reduction of a policy to obtain air pollution benefits. In fact we are able to shed some light on that question as well in one of our sensitivity analyses, but it is not our main focus.

A possible benefit for a developing country joining a climate treaty is that of emission sales. If the country commits to emissions at the level implied by normal economic development, sometimes called business as usual, it may sell emission reductions at a world market price and gain the benefit of price minus cost. While this paper primarily has in mind the alternative situation that China commits to real reductions we are also able to demonstrate the benefit of emission trading given a commitment equal to business as usual.

We analyze three designs of a climate treaty. A comprehensive treaty in CO_2/GDP intensities represents an avenue for including developing countries that has been widely discussed (e.g., Lutter, 2000; Pizer, 2005). The intensity target is sometimes called a dynamic target since it allows countries to adjust their emission reduction in response to economic growth. China of course has high growth ambitions, but at the same time it has a stated goal of reducing its energy intensity by 20% in the period 2006–2010. A dynamic treaty in intensities accommodates the principle of these twin goals.

A treaty in levels is a continuation of the Kyoto Protocol. This makes it the starting point in current negotiations. Faithfully implemented the treaty in levels has the obvious advantage that it leaves no uncertainty of how much greenhouse gases will be emitted to the atmosphere, and it is actual greenhouse gas emissions that matter for climate.

The third treaty design we analyzed is a sectoral treaty in intensities. The recent Bali Action Plan (2007) mentions "Cooperative sectoral approaches and sector-specific actions" as a way forward. A sector-based treaty has previously been articulated by, e.g., the Center for Clean Air Policy (Schmidt et al., 2006). It has similarities to a treaty based on technology standards (e.g., Barrett, 2006; Buchner and Carraro, 2005), which in practice would focus much of its attention on improving energy intensity

[1] Formally our analysis is one of tax reform, the tax in question being the CO_2 tax. Analyzing tax reform given the state of the current tax and regulatory system, in this case one where co-benefits are not harvested, is good practice in the tax reform literature, see, e.g., the authoritative survey of Drèze and Stern (1987).

in heavy emission industries like power and manufacturing. The EU trading system is confined to power and manufacturing, to further show the relevance of focusing these industries.

To analyze the costs and benefits to China of joining a climate treaty we use a dynamic computable general equilibrium (CGE) model with environmental features. The CGE model provides an estimate of impacts of a climate treaty that complies with the input–output structure and the overall constraints of the economy, while allowing for the kind of substitution and adaptation to policy that characterizes a dynamic economy. The analysis emphasizes the economy as a driver of environmental change and certain feedbacks from the environment to the economy are allowed as well. In this fashion the model gives a holistic picture of the impact of a climate treaty on China. The price that must be paid for a holistic picture is a lack of attention to the details of technologies, policies and particulars of markets in the economy. The CGE model provides a top-down perspective that complements the bottom-up perspective offered by other methodologies.

CGE models have been used previously to study impacts of CO_2-emission cuts in China. With a previous generation of the model of this paper Aunan et al. (2007) find that China in 2010 may reduce its CO_2-emissions between 15 and 20% before costs outweigh benefits. While other studies emphasize benefits to public health, Aunan et al. argue that increases in agricultural yield, allowed by lower ozone formation, may be equally important. The finding of 15–20% free cut in CO_2 arises because the increase in agricultural yield is added to the health benefit. Without it the reduction is only 5%. Other CGE-based papers shedding light on the impacts of a climate commitment include Garbaccio et al. (1999), Glomsrød and Wei (2005) and Ho and Jorgenson (2007).

The model of the present paper builds on Aunan et al. (2007), but we add several new features. For instance, we add distributional features and are able to perform a fairly elaborate distributional analysis. We distinguish between three regions of China: Guangdong Province, Shanxi Province and Rest of China. Distinguishing three regions allows a richer regional analysis than was possible previously. Guangdong Province is modern and trade oriented with one of the highest GDP/capita levels in China. Shanxi Province has below average incomes and relies on energy intensive industry and mining. It is the province in China that produces by far the most coal. The possible negative impact of a climate treaty on Shanxi Province and similar provinces is a main concern for China. Although some of the concern is grounded in fear of short term unemployment and failed investments, other reasons for concern are structural and long term. We are able to address these structural reasons for concern. As another improvement over previous work the model considers 14 household categories per region, facilitating a distributional analysis within regions as well as between regions. We distinguish the very poor households, including the 200 million people whose consumption was below 1.25 dollar a day in 2005 (Chen and Ravallion, 2008); and the very rich households that make up the Chinese urban upper class. Altogether the 42 household categories cover the economic spectrum in China.

On the environmental side we present improved emission factors for CO_2 compared to previous work. While previous work has relied heavily on international evidence and/or limited the analysis to energy related emissions, the present analysis relies on Chinese evidence and includes process emissions, which are large particularly in the cement industry. Finally the environmental health damage estimates of the model have been updated with recent Chinese and international research, and updated values for environmental damage have been added. The main changes compared to Aunan et al. (2007) are that the impact coefficient for chronic bronchitis has been reduced by a factor of five and the size of the urban population included in the estimates has been increased. The changes to the environmental aspects of the model should improve the precision of our benefit–cost estimates compared to earlier efforts.

2. The model

Our CGE-model belongs to a family of CGE-models used extensively over the past two decades to analyze environmental policy and other policy reforms. In China the model is used in regional development planning and macroeconomic planning for the State Council, including the 5-year plans. Internationally the model has been used for trade policy analysis (Zhai and Li, 2002; Vennemo et al., 2008), labour market reform (Hertel and Zhai, 2006), pension reform (Wang et al., 2004) and

Table 1
Main features of the environmental CGE-model.

Time recursive model with neoclassical closure
64 industries, of which 10 are agricultural, 32 are manufacturing and 12 are service
5 factors of production
Nested CES production system
3 regions with urban and rural areas
7 rural and 7 urban households in three regions, for a total of 42
ELES private consumption system
Imperfect factor mobility across regions and areas
6 energy goods
7 pollutants to air (including SO_2, NO_x, PM_{10}, CO_2)
9 health damage end-points
7 crop damage end-points

environmental policy analysis (O'Connor et al., 2003, Aunan et al., 2007). The model is maintained at the Development Research Center of the State Council in China. Table 1 summarises main features of the model version used in this paper. For equations and a detailed description in English see Vennemo et al. (2008).

With the aid of Table 1 we briefly review the main features of the model that influence on results. We then explain new features of the model compared to previous generations.

3. Main features of the model

The model is time recursive, which means that investment and saving are not explained by expectations of the future, but by history. It has neoclassical closure, which means that total saving determines total investment. Time recursiveness and neoclassical closure imply that the capital stock will in general evolve differently in different scenarios, which could be unfortunate for normative analysis. The economy usually does better the higher is the capital stock, but if a build-up of capital in response to some policy is merely a side-effect of time-recursiveness, it introduces a disturbance into the analysis. To avoid this disturbance as much as possible we tie up foreign saving (the current account), government saving and corporate saving as exogenous, leaving only household saving to contribute to changes in the capital stock.

The model has a large number of industries. The large number of industries allows more precise modelling of structural change in the economy. Structural change is a significant driver of, e.g., changes in the macro-energy efficiency, which it is quite important to capture in the analysis. Fisher-Vanden et al. (2004) have shown the significance of modelling structural change in some detail, or else too much of the structural response to policy is subsumed in residual productivity growth changes. The particularly large number of agricultural industries is partly explained by our wish to model impacts of ozone formation on agricultural yields. Arguments for a large number of industries have to be balanced against arguments in the opposite direction (e.g., large number of technology parameters without empirical backing), which explains why we have not disaggregated even more.

To avoid the well-known specialisation problem of foreign trade the model assumes that there are transaction costs of transportation, logistics, marketing and bureaucracy associated with switching production from the provincial home market and over to markets out of province and internationally. The models uses Constant Elasticity of Transformation (CET) functions to imperfectly capture these costs, with elasticities of transformation of 3.0 between export and domestic production, and in a second nest, 5.0 between in province and out of province. On the import side so-called Armington functions are used with the parameters being the same. The parameters are chosen in order not to exaggerate the unspecified transaction costs.

Industries use the primary inputs capital, land, agricultural workers, production workers and professionals (nested constant elasticity of substitution (CES) functions). Agricultural workers and production workers are interchangeable. Land is, however, reserved for agricultural industries. Professionals are reserved for manufacturing and service industries. The model distinguishes between new capital, that is the current vintage of investment, and old capital, that is non-depreciated

Table 2
Guangdong and Shanxi Province compared.

	Nation	Guangdong	Shanxi
Population (million)	1307	92	34
Consumption expenditure per capita (Yuan)	5400	9800	4200
Ratio of urban to rural per capita consumption	3.7	3.5	3.3
Energy consumption ((ton standard coal equivalents)/gross regional product (GRP))	1.1	0.8	3.0
Share of secondary (manufacturing, construction and power) industry in GRP	55%	51%	56%
Output of major industrial products (2004)			
Coal (2005)	100%	0%	18%
Steel	100%	3%	4%
Cement	100%	8%	2%
Chemical fertilizer	100%	0%	5%
PM10-emissions (soot) (kg)/capita	9	3	33

Source: 2005 data from NBS (2006) except 2004 data on steel, cement, chemical fertilizer from NBS (2005).

investment of last year and before. Old capital is almost fully locked to production in the industry where it was invested. New capital can readily be substituted between industries and against other production factors. O'Connor et al. (2003) give details of the elasticities of substitution that are used. In addition to primary inputs, industries use intermediate inputs according to a 64-industry input–output matrix derived from regional SAMs for the base year 1997.[2,3]

4. Three regions

The model distinguishes the economies of Guangdong Province, Shanxi Province and the Rest of China. Both Guangdong Province and Shanxi Province have particular features of interest from an environmental perspective, see Table 2.

Guangdong Province has a population of 92 million. Its consumption expenditure per capita is almost twice the national average. Its energy consumption relative to production is 30% *lower* than the national average. Hence its production is quite energy efficient. The primary reason for its high energy efficiency is that individual industries are efficient. The share of manufacturing industry in Guangdong more or less equals the national average, indicating that composition effects are not the reason. For instance, Guangdong Province produces 8% of all the cement in the nation, and has a large car industry. Despite an average manufacturing share its PM_{10} emissions per capita is only one-third of the national average. In summary Guangdong Province is an affluent and clean province in China.

Shanxi Province has a population of 34 million. Its per capita income is lower than the national average and its consumption expenditure much lower. Its income depends on the price of coal and in fact it used to be even lower until the price of coal recently picked up. The province produces about 20% of all the coal in the nation, and in addition it is home to several energy intensive industries such as steel, chemical fertilizer and aluminum. As a result its energy intensity is almost three times the national average, and its rate of PM_{10} emissions per capita is almost four times the national average. In summary Shanxi Province is a low-to-medium income and dirty province in China.

5. 42 households

In both Guangdong and Shanxi Province and in the nation as a whole, incomes are three to four times higher in urban than in rural areas, and sources of income are very different. Data for sources of income as well as income levels, composition of income and other relevant differences between households in China have been assembled by urban and rural household investigation teams. 36,000

[2] Input–output tables in China are published every 5 years. The 2002 regional tables were available in 2006, but they have some weaknesses, not least on the energy side that are difficult to overcome. See also footnote 9.

[3] Chinese Yuan is the currency used in this paper. In 1997 one Yuan equaled about eight USD. Currently it is around seven USD.

urban households and 68,000 rural households in all provinces were interviewed. In the model these micro-data are sorted by income and aggregated into the seven plus seven categories per region. Each group of seven consists of 10, 10, 20, 20, 20, 10 and 10% of households by income. That is, the 10% of rural households in Shanxi Province earning the least are grouped together, as are the 10% of rural households in Shanxi Province earning the most, and the other groups are distributed in-between. In each group, income is the sum of agricultural-, production- and professional labour income, land return, capital return, distributed enterprise profits, minus taxes on these items, plus transfers from the government and rest of the world. The relative importance of each type of income differs between groups, as does the share of income paid in tax. Consumption and savings are modeled as an extended linear expenditure system (ELES) with group-specific subsistence consumption parameters.

6. Migration within and between provinces

The model allows migration subject to barriers, within and between provinces. In China, barriers to migration include the household registration regime, discrimination in employment, education, social security, etc. In particular it is difficult for a peasant to access the urban market for well-paid, skilled labour. On the other hand, it is often comparatively easy for a peasant to be accepted for unskilled industrial work (e.g., Hertel and Zhai, 2006), typically as a temporary urban migrant. To model barriers to migration we assume that labour flows freely between agriculture and unskilled work in the same province. We assume there is no migration between agriculture/unskilled work on the one hand and skilled professional work on the other hand. In consequence there are two labour markets, and the labour supply pool is much larger for unskilled work than for skilled work. These assumptions confirm with stylised facts of the "Chinese miracle".

Labour migration between provinces is induced by wage differentials. Assuming that members of the labour force differ in their opportunities and attitude with respect to provincial migration we assume that 1% wage differential induces 1.2% migration (CET-function). The elasticity of 1.2% is based on Borjas (2003) and adapted by DRC to Chinese conditions. Here and elsewhere in the model we follow the CGE-convention that endogenous responses follow in the same year as exogenous impulses, and there are no lags.

In the capital market we assume that capital is invested in the province of the savers. The model also incorporates central and regional governments and two categories of public balances, as is the case in China: a government balance collecting taxes and an off-budget public balance collecting fees.

7. Emissions

The modeling of CO_2-emissions has undergone major changes from that documented in, e.g., Aunan et al. (2007). There exists no official CO_2-inventory in China so basically one needs to construct one for the purpose. To estimate CO_2-emissions we distinguish between energy related emissions from industries and households, power sector emissions, and process emissions from cement. To calculate energy related emissions from industries and households we rely on energy balances for 1997 made available by NBS (2004). These particularly detailed energy balances were produced for an international cooperation project and give us energy use of different kinds per industry plus households. The energy balances are linked to the six energy goods of the model (coal, crude oil, natural gas, other gas, refined petroleum, and electricity). We then construct energy related emission factors per industry using the approach recommended by IPCC.[4] For power production we use the IEA (2006) default value for China, 826 g/kWh. While some readers familiar with emission factors from coal fired power plants may find this value low (corresponding to a high efficiency of coal-based power

[4] This approach uses the formula $Ef = EF \times En(1 - cs) \times ox \times (44/12)$, where EF is the emission factor for carbon in units of Joule (or Terra Joule, TJ), En is energy consumption in TJ, cs is the ratio of carbon stored (zero assumed since energy for feedstock is included in En), ox is the rate of carbon oxidized (one assumed), and 44/12 is the molecular weight of CO_2 relative to carbon. Using the energy accounts we add different energy carriers of an industry together to the relevant energy concept, coal, crude oil, natural gas, etc., of the model. Finally we convert the emission factor from "per TJ" to "per RMB Yuan" using the ratio of energy consumption in RMB Yuan from the Social Accounting Matrix, and physical energy from the energy accounts, all per energy carrier.

Table 3
Health damage end-points and impact factors.

End point	Coefficient of relative risk	New cases per million at concentration = 100 μg PM_{10}/m^3
All-cause mortality	0.073	3.5
Chronic bronchitis	0.0048	7.1
Respiratory hospital admissions	0.0012	7.2
Cardiovascular hospital admissions	0.00070	2.8

plants), it should be remembered that around 15% of power production in China is hydro (BP, 2008). For process emissions we concentrate on the largest emission source by far, the cement industry. We use tools available at the website www.ghgprotocol.org to develop the process emission factor for the cement industry.[5] Our estimate of total emissions, 3035 million tons for 1997, is about 90% of Chinese emissions estimated for 1997 by WRI (2008), and 90% of emissions estimated for 1995 by IEA (2007). These sources present aggregate emissions only and the reason for the discrepancy is unknown.

SO_2 emission factors also start off from energy statistics of 1997. Data for sulfur content in fuels were gathered from Yu (2006) of Tsinghua University, and from the Rains Asia database.[6] Emission factors for NO_x and PM_{10} at the industry level are so far not available in China. We make use of the factors employed by Aunan et al. (2007). The model can also produce emission estimates of NMVOC, CH_4 and N_2O. These are not reported here.

8. Environmental damage and cost

The environmental part of the model follows the so-called impact pathway approach, where a path is specified from economic activity, through emissions to air and dispersion, to physical damage and further to economic valuation of damage. We specify one path to health, and another to agricultural yields. The agricultural pathway originates with NO_x-emissions and links back to the economic model. The agricultural pathway is described in O'Connor et al. (2003) and Aunan et al. (2007), and we do not elaborate it further here. We use updated figures for agricultural production in 2000 provided by IIASA (Fischer, 2006). The production figures are aggregated from county level data compiled by the Ministry of Agriculture and National Bureau of Statistics.

The pathway to health originates with particle emissions and through dispersion and exposure it links forward to exposure–response and further to valuation of damage. While the model of dispersion follows Aunan et al. (2007), the exposure–response model has undergone several changes. We base our exposure–response methodology on World Bank (2007), which is a comprehensive study of environmental costs of economic activity in China. World Bank (2007) refers to Aunan and Pan (2004) and HEI (2004) as well as Chinese-language papers. Particulate matter (PM_{10}) is the sole causal agent considered. All-cause mortality, chronic bronchitis, respiratory and cardiovascular hospital admissions are the end-points considered, cf. Table 3. Other end-points, such as outpatient and emergency room visits, work day loss and asthma attacks that have been considered in previous work, are not included here for the primary reason that their impact coefficients are not based on Chinese evidence.

The estimate of the impact on all-cause mortality refers to acute and chronic pathways; see World Bank (2007). The function is log-linear in relative risk, which means that the number of excess annual cases is higher when the baseline concentration is lower. For instance, at 50 $\mu g/m^3$ PM_{10} the impact of 1 μg PM_{10}/m^3 increase is 7.3 excess deaths per million, while at 100 $\mu g/m^3$ (somewhat lower than the urban average in China) the corresponding increase is 3.5 (using the 2002 urban mortality rate in

[5] The formula is $Ef = ClCe \times RwCl \times Ca(44/100)$, where ClCe is the clinker-to-cement ratio, RwCl is the raw material-to-clinker ratio, Ca is the $CaCO_2$ equivalent-to-raw material ratio, and 44/100 is the molecular weight of CO_2 relative to $CaCO_2$. Default values are used for the ratios. To convert to the monetary unit we need production of cement in tonnes, which is obtained from China Statistical Yearbook 2000.

[6] The formula is $Ef = 2 \times s(1 - r) \times (1 - n)$, where s is the sulfur content, r is the rate of retention of sulfur in the ash, and n is the abatement rate. 2 is the molecular weight of SO_2 relative to sulfur. In addition to estimates of s explained in the text we obtain estimates of r from USEPA AP42. n is calibrated to zero in 1997, but is gradually increased over time.

Table 4
Values of health damage end-points.

End point	Guangdong	Shanxi	Rest of China
Mortality risk	900,000	270,000	460,000
Chronic bronchitis	0.4 × mortality risk	0.4 × mortality risk	0.4 × mortality risk
Respiratory hospital admissions	5400	5400	5400
Cardiovascular hospital admissions	9000	9000	9000

Note: Yuan values as of 2003. These are backdated to 1997 prices in the model.

China from Ministry of Health (2004)). The inclusion of chronic mortality increases the estimated impact compared to some previous efforts. Ho and Jorgenson (2007) and Aunan et al. (2007) only consider acute mortality and find 1.95 and 2.2 excess cases, respectively. On the other hand, World Bank (1997) assumes 6 excess cases.

The exposure–response relationship for chronic bronchitis applied here assumes 7 cases per million and per $\mu g/m^3$ PM_{10}, which is low compared with other authors. For instance, Aunan et al. (2007) assume 34 cases. Ho and Jorgenson (2007) refer to World Bank (1997) and assume 61 cases. The difference from 34 or 61 down to 7 matters since chronic bronchitis usually is given a high value in the economic assessment. The main reason for the lower estimate used here is that World Bank (2007) estimates a considerably lower annual incidence rate for chronic bronchitis than earlier studies. The World Bank (2007) estimate is based on data (for 2003) from the Ministry of Health (2004) for prevalence rates of 'aged chronic bronchitis' in English translation, which presumably refers to severe cases that have a long duration. The estimate of 7 thus corresponds to a serious case of chronic bronchitis that basically lasts for the rest of one's life. This definition is consistent with the valuation assumption.

We also assume an impact on respiratory hospital admissions that is lower than, e.g., Ho and Jorgenson (2007) and World Bank (1997). While the percentage change per $\mu g/m^3$ is similar to findings in Europe and the USA, the reason for the somewhat low absolute exposure–response relationship given in Table 3 is that World Bank (2007) assumes a baseline rate of hospital admissions from respiratory and cardiovascular disease that is low by international standards. It should be added that data for disease specific hospital admissions are not normally released in China and the figures we use are uncertain.

In order to compare benefits to costs it is useful to value health benefits. The values we use are given in Table 4. Our main source for value estimates is World Bank (2007).

Mortality risk is valued using the adjusted human capital method, which calculates mortality risk based on foregone lifetime earnings. Following World Bank (2007) GDP/capita is the indicator of earnings, and it is applied to income earners and non-earners alike (hence the name adjusted human capital method.) Since GDP/capita differs between provinces, the value of excess mortality risk also differs. Other important assumptions are 7% future economic growth per capita, and 8% discount rate, compounded over 18 years, which is the estimated average number of years lost per excess premature death (World Bank, 2007).

A major weakness of the adjusted human capital method is that it is not founded in welfare economics, which of course prescribes that the counterpart to prices is willingness to pay. The willingness to pay for risk reduction translates to a value of statistical life. While estimates of value of statistical life do exist in China (see, e.g., Vennemo et al., 2006 or World Bank, 2007 for reviews) the adjusted human capital estimates are more readily accepted and probably the most useful yardstick for valuing mortality risk in a politically acceptable way. The adjusted human capital values are endogenously updated in the model since foregone earnings increase with economic growth.[7]

For chronic bronchitis we follow World Bank (2007) and assume that the value of risk of (serious) chronic bronchitis is 40% of mortality risk. World Bank (2007) cites economic risk-gambles and estimates of the quality of life when living with chronic bronchitis (quality adjusted life years, QALY) as the basis for their 0.4 estimate.

[7] We make no attempt at reconciling the 7% per capita economic growth assumed for the AHC estimates with the endogenous projections from the model. However, as will be seen below baseline economic growth projected by the model is 7.4% annually.

For hospital admissions we follow the cost of illness approach, and the estimate equals the estimated cost of treatment. This is an extremely cautious estimate since we in effect assume that the disease is no worse than the cure. However, absent studies of willingness to pay to avoid hospital admissions from the diseases in question the cost of illness approach seems the best we can do. World Bank (2007), citing evidence from health statistics, present separate cost of illness estimates in large, medium and small cities. We average over those and index the estimate to wage growth.

9. The baseline scenario

Consistent with current policy documents we expect growth in real GDP to average 7.4% annually over the period 2006–2020. Growth in capital input has been considerably higher than growth in GDP in recent years and we expect the trend to continue. Hence capital input is expected to grow 8.1% annually on average. Labour input is expected to grow only 0.3% annually on average, reflecting demographic trends. In most industries total factor productivity is expected to grow 2.4% annually, which is high by international standards, but broadly agrees with estimates from China.[8] In energy mining (coal, natural gas and petroleum) we assume zero productivity growth, which is consistent with econometric evidence in China (Li et al., 2008). We allow an additional 1% growth in the so-called autonomous energy efficiency indicator (AEEI). Some would consider 1% AEEI low given China's high economic growth rate, but one should remember that the AEEI is added to TFP growth. The baseline scenario actually shows an annual improvement in the fossil energy intensity of 4.7%. That is slightly lower than the 1980–2000 experience of China, but much higher than the recent experience 2000–2007 (e.g., Vennemo et al., forthcoming) and higher than China's goal for the 2006–2011 period of 4% per year. Since TFP and AEEI are important and uncertain parameters we perform sensitivity analysis with respect to them below.

These are the national estimates of economic growth and its determinants. Growth in Guangdong Province is expected to be higher; 10.3%. Growth in Shanxi Province is also expected to be high; 8.3%. Again the growth rates are primarily fuelled by capital, but in Guangdong we also expect labour immigration for a 2.2% annual growth in the labour force.

10. Industrial reallocation and household urbanization

As the economy grows, it also restructures. Typically the agricultural share declines in GDP, while the service share grows. We find restructuring in our baseline scenario as well. During the 1997–2020 period agriculture ("primary industry" in Chinese statistics) declines from 19 to 11% of Chinese GDP while the service sector (tertiary industry) increases from 28 to 41%, see Fig. 1.[9]

From a peak of 54.5% in 2004 the share of secondary industry (manufacturing and utilities) ends up at 48% in 2020. In an international perspective 48% is a large share. The large share reflects China's position as a manufacturing center of the world, or in other terms export demand, plus it reflects the country's high savings and investment share, which stimulate construction and heavy manufacturing industry. The comparatively high share of manufacturing industry suggests comparatively high emissions to come.

Along with the emphasis on industry and service, urbanization increases from the current 40 to 60%. This increase is important for health damage from air pollution since it is the urban population that is exposed to damage.

[8] Tfp-growth in China has been the subject of extensive study, but the evidence is not conclusive. Our estimate is in line with Nogami and Li (1995), who estimate 2.40% for the 1977–1992 period, Wang and Yao (2001), with 2.3% for 1978–1999, and Islam et al. (2006), 3.0% for 1978–2002. Other tfp-growth estimates range from a pessimistic 1.4% (Young, 2003) to an optimistic 5% and more. He and Kuijs (2007) and Islam et al. (2006) contain useful surveys.

[9] In the early-2000s China undertook a major revision of its national accounts, which increased the share of services in GDP. We do not make use of the revision, for the following reasons: (a) only macro-indicators were revised, not input–output coefficients, etc., (b) key provincial data were not revised. According to the revised GDP figures the tertiary industry share of China's economy reached 40% in 2001 while the secondary industry share was 45% that year.

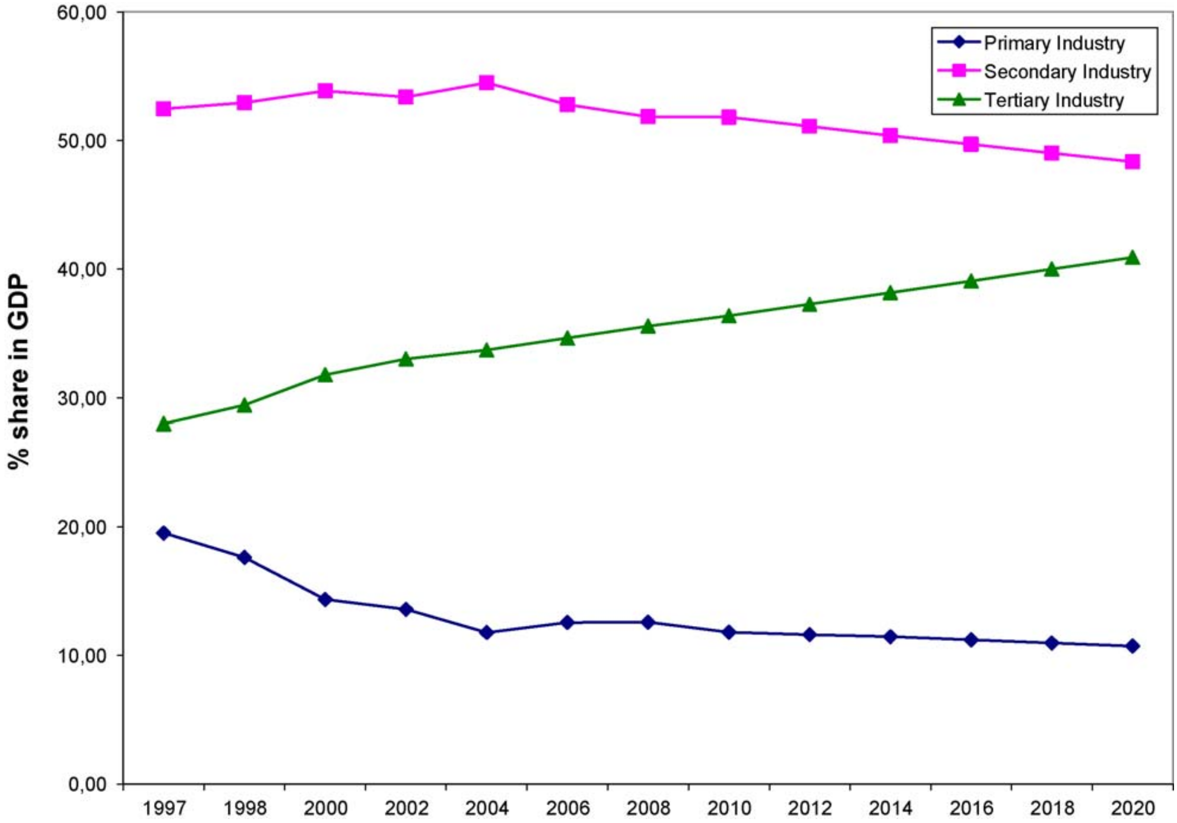

Fig. 1. Industrial restructuring over time.

11. Environmental consequences

Investment driven economic growth, modest industrial reallocation and ambitious urbanization have implications for the environmental footprint of the Chinese economy. We expect all emissions to air to grow to in the 2006–2020 period, but as Fig. 2 illustrates, emission growth falls short of the 7.4% growth in GDP.

CO_2 is expected to increase 2.4% annually over the 2006–2020 period. SO_2 is expected to increase 1.7% annually. PM_{10}, which we recall is important for health risk, is expected to increase 2.1% annually. NO_x, important for the agricultural pathway from the environment to the market economy, is expected to increase 4.3% annually. Its growth is high since NO_x is tied to rapidly increasing private transport.

There are two main reasons why economic growth increases faster than emissions. One is productivity growth, which allows the economy to increase production per unit of energy input. Productivity growth accounts for 3.4% of the 5% difference in growth between GDP and, e.g., CO_2. Industrial relocation is the other reason for the difference, covering 1.6% in the case of CO_2. In addition, the baseline assumes exogenous reductions in SO_2 and PM_{10} emission factors as time goes by: 0.15% annually for SO_2 and 0.25% annually for PM_{10}. These reductions allow us to account for the improvements in end-of-pipe technology, e.g., flue gas desulphurization for SO_2 and electrostatic precipitators for PM_{10}, that may be expected in China. Over much of the last 20 years the emission-per-energy factors have declined more than assumed here, but the decline has halted in recent years.

12. A treaty in CO_2 intensities

While the Kyoto Protocol is based on emission targets in levels, the idea of emission targets in intensities has gained attention lately. An emission target in intensities allows a country to pursue additional economic growth without punishment in the form of additional CO_2-abatement. This feature makes the intensity target a priori attractive for developing countries such as China that hope

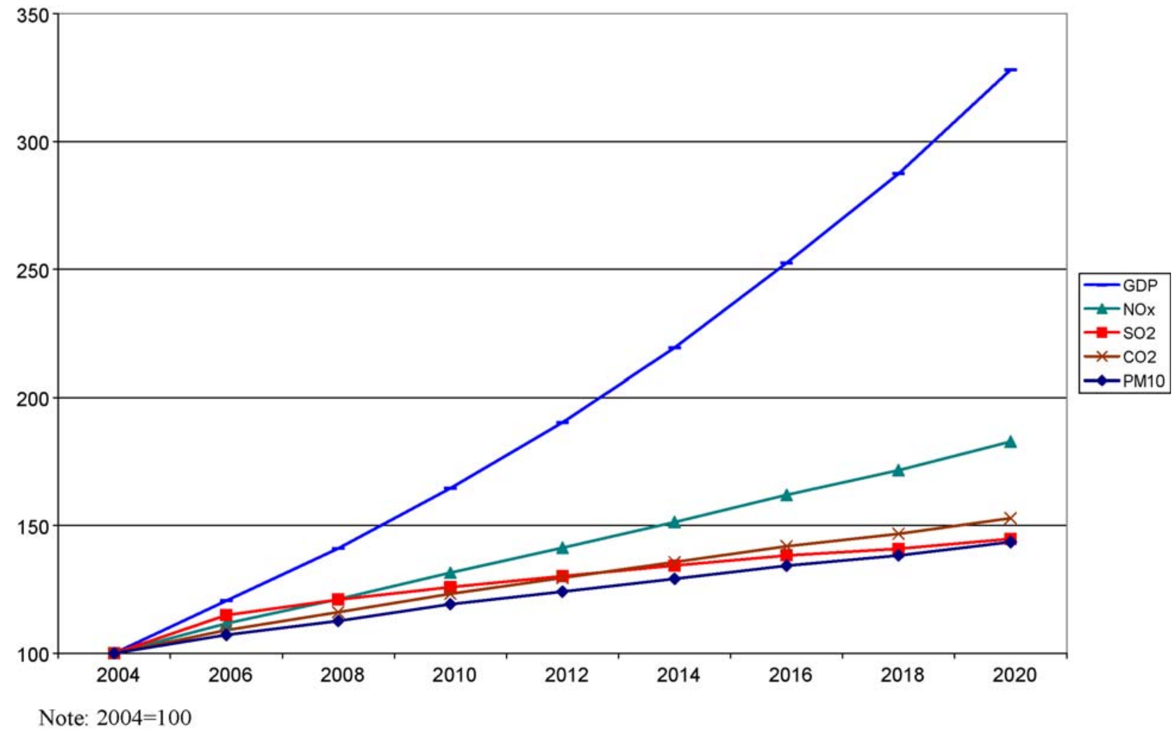

Fig. 2. Growth in GDP and emissions over time. *Note*: 2004 = 100.

for high economic growth. The intensity target has of course also been embraced by some developed countries, notably the U.S. On the other hand, a disadvantage of the intensity target is that a country with a high growth rate is allowed to emit more CO_2 than a country with a low growth rate and the same intensity cap. Some would see this as unfair since the high growth country has more resources available for abatement (e.g., Aldy, 2004).

Our version of a comprehensive treaty in CO_2 intensities is characterized by the macro CO_2/GDP ratio being lower than in baseline 2020. Fig. 3 shows the CO_2 intensity under our version of the treaty and during the baseline, respectively. Recall that in the baseline the intensity falls (improves) 4.7% annually. In the treaty scenarios the fall depends on the ambition of the treaty. A 30% ambition implies an annual 6.9% fall in the intensity.

In this section we assume that a treaty in CO_2 intensities is implemented in a cost effective way, that is, all emission sources face the same shadow price of CO_2. Cost-effective implementation of the treaty is a default assumption that does not stack the deck against it. Concretely we assume *either* a uniform CO_2-tax on all emission sources *or* a national system of tradable permits, with tax or permit revenue returned to industries and households. The tax and permit systems are theoretical equivalents in a non-stochastic setting such as this. While current policy in China relies on regulations and campaigns as well as economic incentives, the country is experimenting with permits and fuel taxes to strengthen incentives for energy efficiency. Later we will contrast the impacts of the CO_2-tax/permit with the impacts of a tax/permit on SO_2.

12.1. Incidence effects

Although everything happens at once in a simultaneous economic model it is sometimes instructive to envisage impacts as if they occurred in sequence. When a tax/tradable permit is introduced in the economy in order to save CO_2 one may envisage that the first thing to happen is that energy prices increase. The increase depends on the carbon content of the fuel and the stringency of the tax. For instance, in the case of a 30% target the model calculates an increase in the price of coal of 46% and an increase in the price of petroleum of 21%, see Table 5.

The next thing one may envisage happening is price increases in the sectors that use fuel. Typically in a market of constant returns to scale the equilibrium price increase equals the cost increase, and

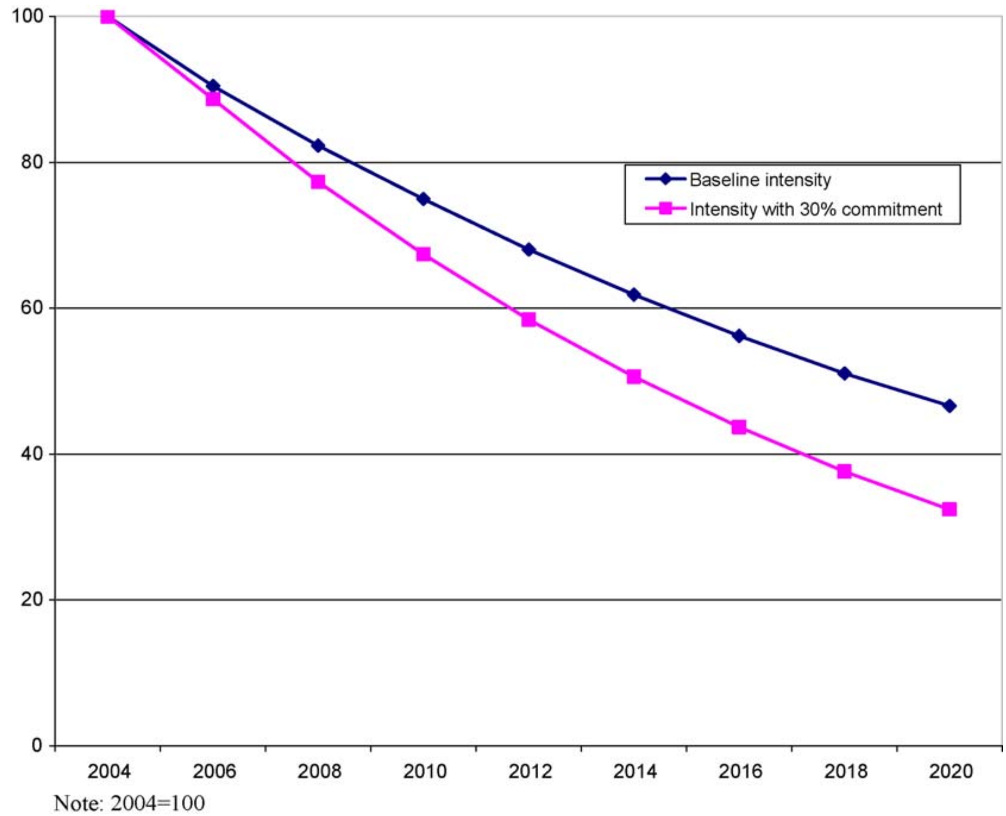

Fig. 3. The CO_2 intensity (CO_2/GDP) in the baseline and with 30% reduction. *Note*: 2004 = 100.

that is what is modeled. From an environmental point of view the most important sector is perhaps electricity generation. Here the price increases 7%. This figure is in our view surprisingly low, but it approximately equals the price hike on coal of 45% times coal's cost share in electricity (18% in the base year). The main driver of cost of electricity is the rental cost of capital. It also helps to curb the price increase of electricity that petroleum is exchanged for coal in about one-fourth of power plants.

The change in energy prices lowers consumption of energy goods. In the case of a 30% CO_2 intensity target coal consumption falls almost 30% while consumption of petroleum falls half of that, 15%. By contrast, electricity consumption holds up very well. One reason is that in many industries, electricity consumption competes with direct use of coal or petroleum. Since the price of coal increases much more than the price of electricity firms prefer to cut down on direct coal consumption rather than electricity consumption. Because there are many technical solutions available for solving energy needs prior to construction of a facility the model assumes large substitution possibilities among energy carriers prior to construction (elasticity of substitution of 2.0 with respect to new investment; 0.2 with prior investment). Firms could of course also cut down on all energy use, but substitution possibilities with respect to total energy are lower (capital-energy elasticity of substitution of 0.8 with respect to new investment, 0.0 with prior investment). The lower substitution elasticities between energy and capital indicate that in many industries energy is essential for production. The elasticities of substitution were originally taken from the OECD Green model. A sensitivity analysis is performed below.

Table 5
Impacts on energy markets.

	Coal	Refined petroleum	Natural gas	Coal gas	Electricity
Impact on price	46	21	30	31	7
Impact on consumption	−29	−15	−19	−21	−1

Note: Percent impact in year 2020 of 30% lower CO_2 intensity.

The price increases just described lead to lower demand for produced goods and services, which other things equal, lowers demand for labour and capital, and strains the trade balance. But, by assumption demand for labour and capital in the new equilibrium is the same as in the old equilibrium, and the equilibrium trade balance is also the same. To restore demand for labour and capital the relative prices of labour and capital adjust, while their level adjust to a new equilibrium price level consistent with the exogenous trade balance. The domestic price level acts as an implicit rate of exchange since the nominal rate of exchange is the numeraire of the model.

How much do the relative prices of labour and capital change? Nationwide it turns out that the rental cost of capital falls only slightly, <1%, while the impact on the price of labour – the wage – depends. The wage of skilled labour increases and the wage of unskilled labour and agricultural workers declines. The impacts are the greatest in Shanxi Province.

In summary then, the model predicts a large increase in the price of coal, a substantial increase in the price of petroleum and gas, and a moderate increase in the price of electricity. Electricity production becomes cleaner and expands its energy market share at the expense of coal. General production is held up by available labour and capital, and any tendencies for cost-inflation and unemployment are counteracted by capital owners accepting a somewhat lower rate of return, and by a fall in the unskilled wage.

To check this argument we decomposed the reduction in CO_2 into the contributions from the scale of production, the industry composition of production, the energy efficiency of industries and the carbon intensity of energy. In the case of a 30% reduction in the CO_2 intensity we find that the scale of production contributes 3% of the total, the industry composition contributes 16%, the energy efficiency contributes 19% and the carbon intensity of energy contributes as much as 62% of the total. The fact that the economy handles 62% of the change within the energy sector contributes to a modest economic loss.

12.2. Macroeconomic costs and benefits

Using the concepts of economic loss and environmental health gain, Fig. 4 shows the impact in 2020 of reducing the CO_2 intensity. Economic loss is the year 2020 loss in consumption possibilities from limiting CO_2-emissions.[10] Environmental health gain is the year 2020 monetary translation of the gain in mortality, chronic bronchitis and hospital admissions. Net welfare is environmental health gain minus economic loss. Fig. 4 shows that net welfare is positive all the way up to 30% reduction in the CO_2 intensity. This 30% reduction potential constitutes the no-regret potential for CO_2 intensity reduction in China. In other words, the economy may become 30% leaner in terms of CO_2-emissions per output before the cost of CO_2-abatement begins to bite. The optimal reduction in CO_2, that is the reduction that gives the maximum welfare gain, is 15%.

The figure also shows a line for "economic loss without yield gain". That line is the economic loss that would have obtained had we not included in the model the impact on agricultural yields. As can be seen the difference between the two estimates of economic loss is not that big, but the yield gain component does make an impact on the estimated no-regret CO_2-reduction. Without the yield gain the no-regret reduction would have been 20%, which is large, but considerably smaller than 30%.

The one component of net welfare that is economic cost may be compared to GDP. A 30% reduction in intensity gives an economic cost of 255 billion 1997-price Yuan (see Fig. 4), which equals 0.6% of GDP. A percentage reduction of this order is common in macroeconomic analyses of climate change, and reflects the fact that economic growth over the long run is held up by growth in capital and labour input, and by total factor productivity growth, just as we described above. As long as a climate commitment does not change these factors the long run macroeconomic cost is bound to be small.

Given the 0.6% reduction in GDP a 30% reduction in CO_2 intensity is equivalent to 30.6% reduction in the CO_2-level compared to the 2020 baseline. The model estimate of 2020 CO_2-emissions is 6.3 billion

[10] Economic loss is measured as 2020 equivalent variation with disposable income as the base. 2020 is sufficiently far away that the economy realistically has time to restructure, but not too far away to be irrelevant. In model-based dynamic analysis one has to ask whether consumption and income paths cross between the baseline and the alternative. Does consumption start out higher and end up lower, for instance? Here the paths do not cross.

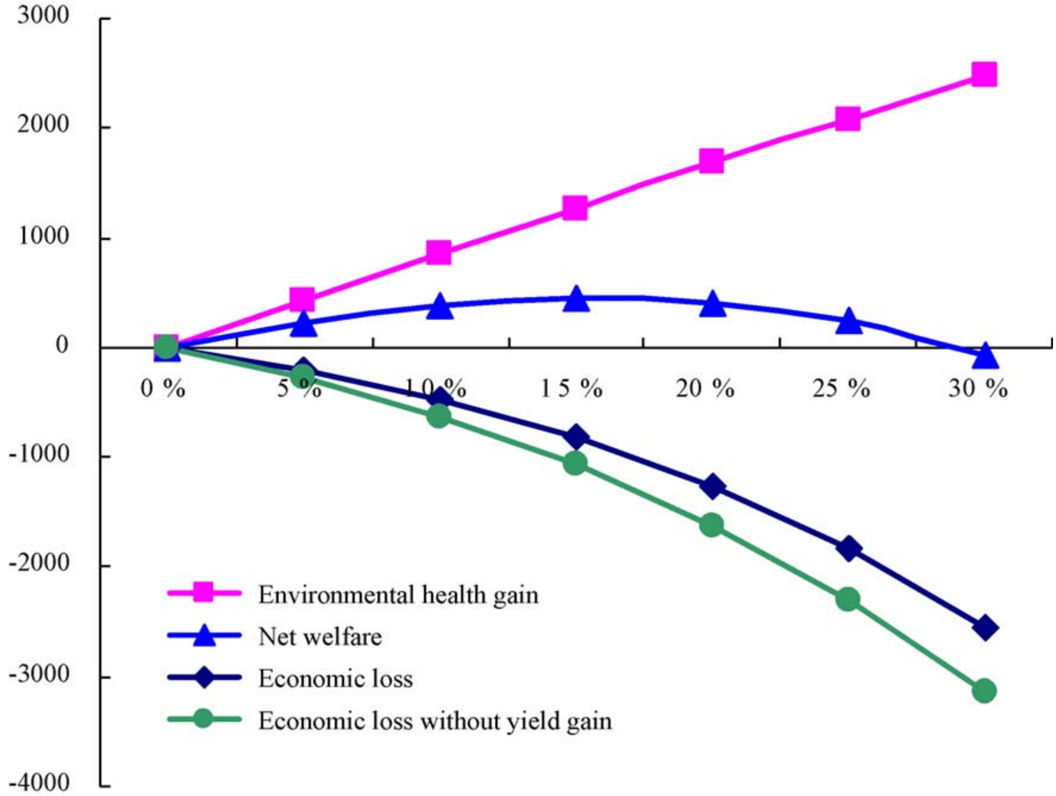

Fig. 4. Economic loss, environmental health gain and net welfare impact of CO_2 intensity reduction. *Note*: Unit is 100 million 1997 Yuan.

tons. Our results therefore imply that China over the long run may reduce its CO_2-emissions by close to two billion tons without regret. That is a formidable number. It is for instance higher than the current CO_2-emissions of Russia, the third largest nation in terms of emissions, and it is equal to half the current emissions of the EU.

Two billion tons lower emissions in 2020 do not mean that model emissions are lower than today. Given the 2.4% baseline growth in emissions the no-regret policy approximately neutralizes the baseline growth since 2006. The implication is that China is equally well off with an incentive (price) based policy to keep CO_2-emissions constant as it is with business as usual CO_2-emission growth.

12.3. Regional distribution of economic loss

There is currently significant concern about the uneven regional distribution of economic growth in China and it is probably more difficult for the country to take on a commitment if it exacerbates uneven regional growth. On this background we study the impact of a climate commitment on regional distribution.

From the perspective of regional distribution it is worrying for a commitment that rich Guangdong fares comparatively well, while poor Shanxi fares comparatively badly, see Table 6. In fact, Shanxi Province stands to lose 10 times the national average.

The reasons Shanxi stands to lose are not difficult to understand. We have emphasized already that the province is home to about a fifth of Chinese coal production, as well as several coal intensive industries. Almost by definition the demand for coal is capped when carbon emissions are capped, and Shanxi Province can sell less coal for domestic purposes. Also, like we have seen, domestic coal fetches a lower producer price since a lower price is the main instrument discouraging the province from production. Shanxi producers are to some extent able to compensate for lower domestic demand by increasing their exports. However, switching to export is costly. Despite export possibilities it is clear that Shanxi Province stands to lose.

Table 6
Regional distribution of economic loss.

	Guangdong	Shanxi	Rest of China
Economic loss	−0.0	−5.8	−0.5
Economic loss without yield gain	−0.2	−6.2	−0.6

Note: Assuming a 30% decrease in CO_2 intensity. Percent impact on welfare (equivalent variation per regional gross products). Not including environmental impact.

12.4. Distribution of economic loss at the household level

We also examine the distribution of economic loss at the household level. Examining national figures first, in the right-hand column of Table 7, we find that well off households fare relatively better from a CO_2 intensity commitment than poor households. That is evident when we compare rural and urban households, recalling that urban household income is approximately 3.5 times higher than rural household income: the median urban household loses an equivalent of 0.8% of income while the median rural household loses 60% more. This masks differences at the provincial level. In Guangdong Province rural households actually do better than urban households. But in Shanxi Province and in the large "Rest of China" category the national pattern comes through.

The relative benefits of well off households are also evident when we compare well off to less well off urban households: at the national level the well off urban households actually gain from a commitment, while less well off households lose. Similarly for rural households: the least well off rural households, those living on less than a dollar a day, lose more than any other income group. In Shanxi Province this group loses between 5 and 10% of their consumption possibilities, which obviously is a big challenge for any government. Nationwide, well off rural households fare comparatively better.

The distributional impacts are explained by a set of factors including relative compensation to labour and capital, and more prosaically by the mechanism for handing over carbon tax/permit revenue. Recall that a CO_2-commitment brings in tax or permit revenue, which directly or indirectly ends up with households since government savings is fixed. We assumed a proportional reduction in direct tax rates of households. It turns out that it is primarily well off urban households who pay direct tax in China, and the relatively positive outcome for these households is fully explained by the tax-refund assumption. Hence the regressive outcome among urban households is easily remediable and

Table 7
Household distribution of economic loss in CO_2 intensity treaty scenario.

	Guangdong	Shanxi	Rest of China	Nation
Urban				
Lowest 10%	−0.9	−7.2	−0.6	−0.7
Second lowest 10%	−0.7	−5.3	−1.1	−1.1
Lower middle 20%	−0.5	−5.1	−0.9	−0.9
Middle 20%	−0.5	−4.9	−0.8	−0.8
Upper middle 20%	−0.3	−4.2	−0.4	−0.5
Second highest 10%	0.9	−2.3	0.5	0.5
Highest 10%	1.6	−1.1	1.5	1.5
Rural				
Lowest 10%	−0.6	−7.3	−2.0	−2.0
Second lowest 10%	−0.1	−6.7	−1.7	−1.6
Lower middle 20%	0.2	−6.9	−1.5	−1.4
Middle 20%	0.4	−7.2	−1.3	−1.3
Upper middle 20%	0.7	−7.5	−1.2	−1.1
Second highest 10%	1.1	−8.0	−1.0	−0.8
Highest 10%	1.4	−8.7	−0.9	−0.7

Note: Assuming a 30% decrease in CO_2 intensity. Percent impact on welfare (equivalent variation of disposable income per real household income.) Not including environmental impact.

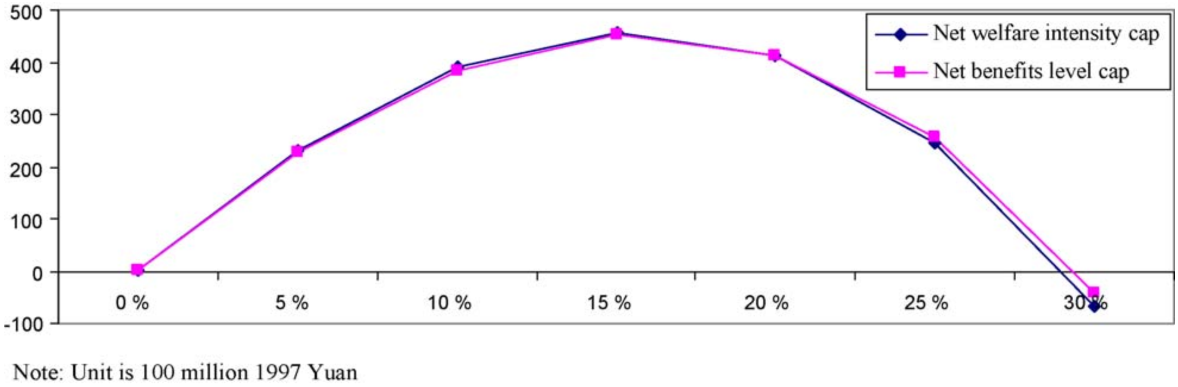

Fig. 5. Net welfare under intensity and level caps. *Note*: Unit is 100 million 1997 Yuan.

not something we would emphasize as a given distributional outcome.[11] By contrast the heavier impact on rural households than on urban households is related to factor incomes, concretely lower wages and incomes for the huge pool of peasants and unskilled production workers. In addition, rural households miss out on environmental health benefits. Some of the damage to rural households could be alleviated if tax revenue were redistributed to rural households, but that is harder than it seems since rural households mostly pay fees and not direct tax, and fees are imposed by local government and often go unregistered. A carbon tax/permit system would probably lead to central government income and have trouble reaching down below the provincial level. There are of course other ways rural households can be supported, including well designed indirect taxation and subsidized housing, education and health, but a study of these possibilities is beyond the scope of this paper.

13. A treaty in levels

An alternative to a treaty in CO_2 intensities is a treaty in CO_2-levels. The levels approach is the approach taken by the Kyoto Protocol and remains the approach of choice not least in Europe. The EU cap-and-trade system is based on targets in levels. A treaty in levels also gives a benchmark for comparing other alternatives such as a comprehensive or sector based treaty in intensities. Hence it is of interest for China to consider the implications of a treaty in levels.

In our analysis there is practically no difference between a treaty reducing the 2020 CO_2 intensities by *x*% percent and one reducing the 2020 CO_2 level *x*% percent (see Fig. 5). The reason is that, e.g., a 30% cut in the macro CO_2 intensity lowers GDP only 0.6%. In other words, a 30% cut in the macro CO_2 intensity equals a 30.6% cut in the CO_2 level.

One cannot always assume that the reduction in GDP is low. If the reduction in GDP is higher, a cut in CO_2 intensities corresponds to a larger cut in the CO_2-level. In this sense a treaty in intensities is always more ambitious than a treaty in levels. Even in our case with a low reduction in GDP the treaty in intensities is slightly more ambitious (−30.6%) than the treaty in levels (−30%).

If one happens to know the reduction in GDP there is a one-to-one correspondence between the two treaty designs. If one does not know future GDP growth this one-to-one correspondence breaks down. We pointed out above that the treaty in intensities gives a safety valve to countries that do not know their future growth rate. If a country does not know its future emission intensity a symmetric argument may be put forward on behalf of the treaty in levels.

14. A sector-based treaty in power and manufacturing

The sector-based approach is currently gaining momentum in climate change negotiations and as noted it is singled out in the Bali Action Plan (2007) as a way to approach "enhanced national/

[11] An alternative to pursue in forthcoming work is to recycle revenue by lowering indirect taxes. China has a VAT on goods. Services are subject to a business tax. In addition there are excise taxes on some goods. Tax revenue is split between the local and central levels with different rules for different indirect taxes.

international action on mitigation of climate change''. The core of the sector-based approach is that a treaty should emphasize CO_2-emission reductions in economic sectors known for high emissions and/or high mobility, typically power production and manufacturing industry. Other elements that sometimes are mentioned include a sector based bottom-up approach to estimating baseline emissions; cooperation on technological improvement in the emphasized sectors, and in the proposal of Schmidt et al. (2006) an ingenious incentive-based approach to emission reductions whereby developing countries gain from selling off fruits of emission reductions that exceed their commitment, but the same countries will not be punished if they fail to reach their commitment.

Here we focus on the core issue of CO_2-reduction in power production and manufacturing industries. A treaty confined to power production and manufacturing industries then differ from the baseline by CO_2 intensities in power and manufacturing being lower than in the baseline. CO_2-emissions from other sectors go uncontrolled. The treaty covers approximately 75% of China's base year CO_2-emissions and includes the main sectoral sources of emissions, such as power production (25% of emissions), cement (20%), and iron and steel (10%). By 2020 the share covered by the treaty has fallen to 67%.

15. Consequences of a sector-based treaty in power and manufacturing

Interestingly, the benefits to public health are much weaker in a treaty in power and manufacturing, than in a comprehensive treaty. In fact health benefits are only 25–30% of a comprehensive treaty, see Table 8. Costs, by contrast, are 65% higher than a comprehensive treaty. The consequence is that a treaty in power and manufacturing gives zero no-regret CO_2-reduction.

Why are health benefits from a treaty in power and manufacturing so low? The reason is that emissions from power production and to a lesser extent manufacturing typically are released from high stacks. In our analysis emissions from high stacks lead to lower health improvement per unit of emission than emissions from low stacks and exhaust pipes. Coming from high stacks they are dispersed over a wide region, but the increment in concentrations in urban areas is low.

It is not unlikely that our model exaggerates the impact of high versus low stacks. Emissions from high stacks contribute to damage in faraway urban centers, and there is also some damage to the rural population. We are not able to capture the quantities involved and assume that impacts are zero in rural areas. Moreover, in contrast to our result of zero no-regret, it is almost always possible if one goes bottom-up to find some no-regret measures in power and manufacturing, see e.g., Mestl et al. (2005) for a demonstration under the condition of zero impacts in rural and far-away urban areas. Therefore, the result of zero no-regret measures is an exaggeration. Still we believe that the model points to a valid tendency, namely that a treaty in power and manufacturing emphasizes emission sources that have low co-benefits.

In terms of cost the model brings out the disadvantage of taxing a narrow base. A treaty in power and manufacturing leaves out one-third of 2020 emissions. Leaving aside one-third of emissions imply that many cheap interventions are excluded from consideration. In effect one exchanges cheap for expensive interventions, and the result is a 65% increase in costs.

We also analyzed the distributional impacts of a treaty in power and manufacturing. The distributional impacts are quite similar to the impacts of a treaty in intensities: Shanxi Province stands to lose, and the impacts at the personal level are mildly regressive.

Table 8
Comparing comprehensive and sectoral climate commitments.

	Environmental health gain	Economic loss	Net welfare
Comprehensive	1679.5	−1265.2	414.3
Manufacturing and power	461.2	−2092.3	−1631.1
Relative	27%	165%	

Note: Comparison made for a 20% aggregate reduction in CO_2. Unit is 100 million 1997 Yuan.

Table 9
Comparing a tax on CO_2 and SO_2.

	Economic loss without yield gain	Economic loss	Environmental health gain	Net welfare
SO_2-tax	−1082	−754	1917	1163
CO_2-tax	−1076	−816	1272	456
CO_2-tax relative to SO_2-tax	99%	108%	66%	39%

Note: Unit is 100 million 1997 Yuan. Reduction in aggregate CO_2 is 15%.

Finally we analyzed a treaty focusing on power production and four high-emission manufacturing industries only.[12] This treaty design covered 60% of baseline emissions. The results are similar to a treaty covering power and all of manufacturing.

16. Using SO_2 as a vehicle for reducing CO_2

So far the analysis of Chinese climate treaty participation has assumed that China introduces a new climate policy instrument to deal with the new policy objective of CO_2 commitment. In practice, it is not unlikely that China makes use of its current main environmental instrument, the SO_2 levy.[13] A tax/permit on CO_2 in combination with a SO_2 levy is also possible. The possible use of the SO_2 levy is supported by two facts: one is that lower SO_2 emissions is a major political aim in China. The second is that the current SO_2 levy is generally thought to be too low to make an impact, and an increase is in the cards. Hence we analyze the consequences of using SO_2 as a vehicle for reducing CO_2.

17. Consequences of using SO_2 as a vehicle for reducing CO_2

The likely prior of an economist comparing the efficiency with respect to CO_2 of a tax on CO_2 compared with a tax/levy on SO_2 is that the CO_2-tax is the more cost-effective since it targets CO_2 directly. The analysis does not confirm this prior. In Table 9 we compare a 15% reduction in the CO_2 intensity by means of a tax on CO_2 and a tax on SO_2. The tax on SO_2 is targeted at a 25% reduction in the SO_2-intensity, but it brings 15% reduction in CO_2 as a co-benefit.

We observe from column no. 1 of Table 9 that the economic loss associated with the SO_2-tax does exceed the loss associated with the CO_2-tax, but the difference is only 1%. One percent is a typical size of an allocation loss in CGE based tax reform experiments and from that perspective it is no surprise. From column nos. 2 and 3, however, we observe that the benefits in terms of impacts on yields and impacts on health are substantially higher for SO_2 than for CO_2. Here it is important to realise that neither the impact on yields nor the impact on health are priced in the market. Since they are not priced they are unpredictable elements of the analysis. It so happens that a tax on SO_2 is more effective at reducing impacts on yields (through associated NO_x reductions) and health (associated PM reductions) than is a tax on CO_2, and this is what carries the analysis. Note that including in the analysis an explicit value of CO_2 does not matter here since the comparison is benchmarked so that both taxes remove the same amount of CO_2. When targeting SO_2 the no-regret reduction in the CO_2 intensity is as high as 36%.

The benefits associated with an SO_2-tax may in fact be even higher than reported here. Emissions of SO_2 are known to contribute to the formation of sulfates, which are part of PM_{10}. The model analysis ignores this pathway, hence probably understating the benefits of SO_2 removal.

The distributional impacts of a tax on SO_2 are similar to the impacts of taxing CO_2: Shanxi Province stands to lose, and household impacts are mildly regressive.

Why does a tax on SO_2 produce higher no-regret reduction in CO_2? First, a tax on SO_2 tends to emphasise low stack emissions sources to a greater extent than does a tax on CO_2. Second, the source

[12] Chemical, building-materials including cement, iron and steel, non-ferrous metals.

[13] Revenue generated by SO_2 levy must currently be spent in particular ways. We do not mean to suggest that an expanded SO_2 levy should obey these spending rules. The model analysis assumes lump sum redistribution inn the form of lower direct taxes, just like in the case of CO_2.

linkage for SO_2 versus PM_{10} and NO_x is closer than the source linkage for CO_2 versus PM_{10} and NO_x. If one had an optimal environmental tax structure in place, including taxes on particle and NO_x emissions, then a tax on SO_2 would not be given the extra boost that it gets now and the CO_2-tax would emerge as the best instrument to reduce CO_2. As noted in the introduction, China is far from this point at present.

This model is not suited for assessing end-of-pipe measures, which is relevant for SO_2-control. This means that while we find 15% CO_2-reduction associated with a SO_2-tax that gives 25% SO_2-reduction, the reality could be that 15% CO_2 is associated with an SO_2-tax that gives 30–40% SO_2-reduction. It is not clear whether that changes the estimate of the economic cost of the tax, or the estimate of the benefits of associated PM_{10} and NO_x reductions. Hence the co-benefit parameters of the SO_2-tax may be unaffected by its inability to capture end-of-pipe.

18. Sensitivity analysis

Based on experience from previous applications of the model (e.g., Aunan et al., 2007; Vennemo et al., 2006) we perform sensitivity analyses on the valuation of environmental health benefits, the possibility for inter-provincial migration, energy related technical substitution possibilities and general (TFP) as well as energy augmenting (AEEI) technical change. Results are presented in Fig. 6 in the form of net benefit curves for the five sensitivities. The net benefit curve of the standard scenario is reproduced for comparison.

Of the five sensitivity analyses it is valuation of health impacts that makes a difference. In the sensitivity analysis for health impacts we assume that environmental values do not increase over time. In other words the elasticity of willingness to pay with respect to GDP changes from unity (in the standard scenario) to zero. This affects results a great deal. Instead of 30% no-regret there is zero no-regret reductions in CO_2. The obvious point behind is that the argument for reducing CO_2 in order to improve environmental health rests on the assumption that an improvement in environmental health has a positive value. The standard scenario makes many conservative assumptions in this respect. For instance, it is based on the human capital approach to valuing mortality risks, which is 50% or less of recent estimates based on willingness to pay (see Vennemo et al. (2006) or World Bank (2007)). It excludes several of the end-points that have been mentioned in previous and current work. But it does assume that the human capital based value of statistical life and other environmental values increase on par with GDP and wages. If one cannot accept that, it follows that there is no positive no-regret level.

Another interpretation of this sensitivity is that environmental values should increase, but the 1997 base should be only one-sixth of what we have assumed in the standard scenario. That is how

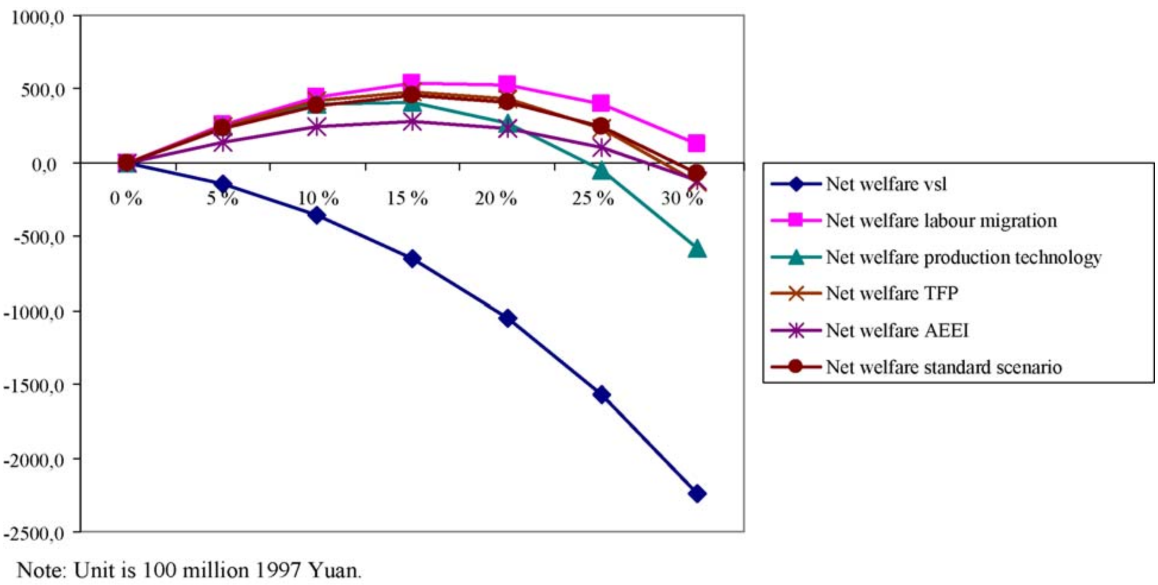

Fig. 6. Net benefits of CO_2 intensity reduction under four sets of assumptions. *Note*: Unit is 100 million 1997 Yuan.

much environmental values fall as a share of GDP if one keeps them constant over time, and therefore it is the relevant correction at the start if one assumes that value increases and still ends up at one-sixth of the standard scenario level. Since our base year values are quite conservative to begin with, we believe there are many arguments why values should *not* be reduced further, but if one can only accept the reduced values it follows that there is no positive no-regret level.

When outlining this analysis we hypothesized that technological parameters and migration also would influence results significantly. It turns out not to be the case. We halved the capital-energy elasticities of substitution and reduced by 25% the within energy elasticities of substitution, but the no-regret CO_2-reduction changes from 30 to 25%, well inside the uncertainty that is reasonable to put on results from an analysis like this. The direction of the effect is as expected since lower elasticities make the production structure stiffer and production cuts must take more of the burden of reducing CO_2-emissions. Furthermore, results are very robust to assumptions about TFP and AEEI.

As the final sensitivity we disallowed migration between provinces. In a macro-perspective that has the effect of decreasing substitution possibilities. The outcome is again a small difference from the standard scenario. Larger impacts are seen in the provinces, especially in Shanxi since a stop in the outflow of workers implies a lower equilibrium wage for those remaining.

19. Conclusion

We have examined the impact on China of different designs of a climate commitment: a comprehensive commitment formulated in the macro CO_2 intensity; a comprehensive commitment formulated in the macro CO_2 level; and a sectoral commitment in manufacturing and power production. We have examined two policy strategies for implementing a commitment: a tax or transferrable permit on CO_2, and a tax or transferrable permit on SO_2. Finally we have analyzed sensitivities with respect to environmental valuation, technological substitution and labour migration.

The almost unanimous message from the analysis is that China could, and for the sake of its own welfare actually should commit to a significant CO_2-reduction. The numbers indicate that the country can reduce CO_2-emissions by a third before costs outweigh environmental co-benefits. It is uncertain how much CO_2 is emitted from China, but we estimate that about two billion tons of CO_2 can be eliminated before costs outweigh benefits. Two billion tons is more than the current emissions of Russia, the third largest emission nation in the world. In fact it equals between 5 and 10% of current global CO_2-emissions. Chinese no-regret CO_2-emission cuts matter a lot even on a global scale.

This is the good news for China—and for the world. The bad news is that CO_2-cuts seem to harm poor rural households more than other groups. In fact we find that a CO_2-reduction of two billion tons may reduce the standard of living of poor rural households in Shanxi Province by between 5 and 10%. It is not unlikely that a similar effect is present in other provinces relying on mining and heavy industry, including several of the western provinces. The negative effect on poor rural households making a living on 1–2 dollars a day emerges from this work as a major policy challenge for China if and when it commits to CO_2-reductions.

A further message from the analysis is that a so-called sectoral commitment is not nearly as positive for China as a comprehensive commitment. The reason is that a comprehensive commitment encourages China to address sectors where CO_2-cuts imply large improvements in environmental health and agricultural yields. A sectoral agreement by contrast, excludes those sectors. Thus the paradoxical situation emerges that a commitment design that is intended to address the needs of China and other developing countries, ends up doing the opposite.

These messages are robust to choice of policy instrument. Actually a formal focus on SO_2 is able to deliver *more* CO_2-reductions for free, since co-benefits turn out to be larger. Further, the messages are robust to sensitivity analysis with the reasonable exception that environmental valuation matters for results. If environmental values fall to one-sixth relative to GDP, which is the case when values are constant over time and we recall that GDP increases sixfold, the no-regret potential for CO_2-reduction vanishes. We consider it unlikely that environmental values should stagnate in this way. If anything well off countries seem to value the local environment more relative to GDP than do poor countries.

Environmental valuation also helps determine the relative impact of the two co-benefits of CO_2-control: environmental health and agricultural yields through the NO_x–ozone-chain. Most previous research agrees that the impact on environmental health clearly is the most important co-benefit. However, our own research in Aunan et al. (2007) found that impacts on agricultural yields are as important as impacts on environmental health. While it clearly is not correct to say that only health benefits matter, the current analysis brings us closer to mainstream previous research. The difference between this paper and Aunan et al. (2007) is that we now look at 2020, where the agricultural share of the economy is lower than in 2010, the focus of Aunan et al. (2007). Hence improvements in agricultural yields matter less. Another significant difference is that Aunan et al. (2007) do not allow environmental values to grow. As we just discussed, that assumption limits the importance of environmental health over time. In our view much more research is needed on environmental benefits in a macroeconomic setting before concluding on the relative impacts of the different benefits.

The results from this research may be used to discuss how China would be affected by emission trading. Assume, for instance, that the country is allowed a commitment equal to business as usual within an intensity treaty. Assume also that the international price of CO_2-emission permits equals 170 1997-price Yuan/ton, which happens to be the price corresponding to a 30% decrease in our intensity scenario. Assume, finally, that there are no frictions in trade. In this situation China will earn income from permit sales at the international price as long as domestic abatement costs are lower than the permit price. Since from Fig. 4 marginal costs are increasing, domestic abatement costs are lower up to a 30% reduction. China's profit from selling off 30% of its emissions turns out to be 28% of costs. In addition, there are of course the co-benefits. The assumption of friction-less trade and a commitment equal to business as usual is just a benchmark, but it indicates that China may gain significantly from a generous commitment in combination with emission trading.

The main message from our research, however, is that China may take on a real commitment and cut its CO_2-emissions by a third without suffering an aggregate welfare loss—with the important caveat that poor rural households in some provinces may be significantly worse off. This message echoes and strengthens the earlier research by Aunan et al. (2007) that the country could cut emissions between 15 and 20%. Considerable microeconomic evidence gives the same message that no-regret possibilities are many. However, distributional concerns must be addressed. A sectoral agreement, which currently is floated in order to help developing countries, seems to have a serious flaw as far as China is concerned and this research does not support the idea of pursuing it further.

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