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Reaping the Economic Benefits of Decarbonization for China

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China needs to reduce its carbon emissions if global climate change mitigation is to succeed. Conventional economic analysis views cutting emissions as a cost, creating a collective action problem. However, decarbonization can improve productivity and provide co-benefits that accord with multiple national policy objectives. We track China's progress in reducing the emissions intensity of the economy, and construct a macro scenario with China's carbon emissions peaking in the 2020s. Investment in greater energy productivity and economic restructuring away from heavy industries can bring productivity gains, and decarbonization of energy supply has important co-benefits for air pollution and energy security. Combined with lower climate change risks and the likelihood that China's actions will influence other countries, this suggests that cutting carbon emissions is not only in China's self-interest but also in the global interest. To properly identify the true costs and benefits of climate change action requires new thinking in economic analysis.

Keywords
China, climate change mitigation, co-benefits

JEL Classification
O44, Q48, Q54.

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Abstract

China needs to reduce its carbon emissions if global climate change mitigation is to succeed. Conventional economic analysis views cutting emissions as a cost, creating a collective action problem. However, decarbonization can improve productivity and provide co-benefits that accord with multiple national policy objectives. We track China's progress in reducing the emissions intensity of the economy, and construct a macro scenario with China's carbon emissions peaking in the 2020s. Investment in greater energy productivity and economic restructuring away from heavy industries can bring productivity gains, and decarbonization of energy supply has important co-benefits for air pollution and energy security. Combined with lower climate change risks and the likelihood that China's actions will influence other countries, this suggests that cutting carbon emissions is not only in China's self-interest but also in the global interest. To properly identify the true costs and benefits of climate change action requires new thinking in economic analysis.

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I. Introduction

Climate change has traditionally been framed as a global common problem arising from climate change mitigation being a global externality, compounded by the long-term nature of the problem. Consequently, climate change mitigation suffers from the classical collective action problem, so nations will not sufficiently coordinate to address the problem to the extent that would be globally optimal. This problem is acute as global greenhouse gas emissions will need to fall to approximately half their current level by the middle of this century to limit future climate change to a manageable level. This will need to be achieved while maintaining strong economic growth, which is a prerequisite for developing countries to prosper.

Mitigation action is traditionally viewed as economically costly, and any costs incurred are viewed as a burden that needs to be shared among nations. Such burden sharing is fraught with difficulty. First, there are significant differences in historical emission among countries, with the majority of accumulated greenhouse gas emissions in the atmosphere from developed countries but almost all of the current incremental growth of greenhouse gas emissions from developing and industrializing countries. Second, distributing the mitigation burden among countries in a way that accords with principles of equity and broadly accepted notions of fairness while minimizing the overall mitigation cost would require large financial transfers between

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countries (Pan *et al*., 2013). Third, the mitigation burden is compounded by the future damages and costs of adapting to climate change, which in many cases may disproportionately affect developing countries with low incomes and limited institutional capacity.

The world's nations are now working towards a new climate change agreement, to be finalized at the December 2015 UN climate conference in Paris. It is predicated on the notion of "nationally determined contributions" to a global effort to reduce greenhouse gas emissions, rather than as a negotiation over how a predetermined overall goal should be shared. This is more suited to a situation where there is not sufficient trust and collaboration to solve the conundrum of burden sharing.

If this approach is to deliver a strong mitigation outcome, nations will need to find their own benefits from taking strong action to decarbonize their economies. For this purpose, countries need to set aside the conventional view of mitigation as imposing only costs on national economies. Instead, nations need to make more broad-based and inclusive assessments of the changes that a low-carbon trajectory brings for their future prosperity (see Zhang, 2014).

Opportunities may be revealed for self-interested action to cut emissions, and for countries to cooperate on the basis of self-interest. International cooperation on climate change could shift from the traditional burden sharing paradigm to a benefit and opportunity-sharing paradigm.

China is the most important player in determining whether the world embarks on this journey. China has experienced a period of extremely rapid growth, with great increases in carbon dioxide (CO_2) emissions and other forms of pollution, and some adverse social consequences. China's leadership has acknowledged this issue in stark terms, with President Xi Jinping indicating that China's current development model is "unbalanced, uncoordinated and unsustainable." (Xinhua Agency 2013b). Whether and how fast China can move towards inclusive, innovative, sustainable and low carbon growth will have major implications for the direction taken by other countries, and for the global climate.

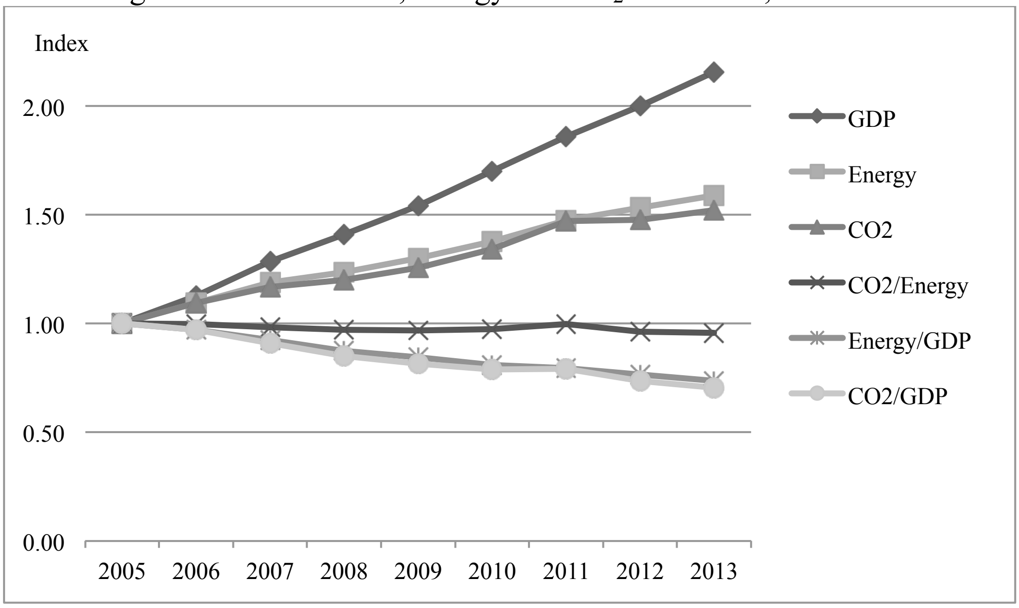
The present paper spells out some of the limitations of traditional approaches, and discusses ways for overcoming them. The rest of the paper is structured as follows. Section II details China's progress towards the 2020 emissions intensity target, and provides macro scenarios for a peak and decline in China's emissions, in the context of historical experience in other countries. Section III describes how reforms to cut emissions can increase productivity and investment returns, thereby contributing to sustainable economic growth. Section IV discusses innovation within the context of growth and climate change, especially as a measure to reduce the risk premium of low carbon technology. Section V focuses on co-benefits of climate policy and discusses the importance of aligning policy goals within a context of multiple policy goals. Section VI concludes.

II. China's Emissions Trajectory

China's rapid economic growth has coincided with rapid growth in energy use. This has caused rapid growth in CO_2 emissions, as the majority of the incremental energy demand has been met using fossil fuels, in particular coal, the most emissions-intensive fuel. China has become the top energy consuming and carbon emitting country in the world, surpassing US energy use in 2009 and US carbon emissions in 2006.

During the period 2005–2013, China's real GDP growth averaged 10 percent per year, primary energy demand increased by an average 6.0 percent per year and CO_2 emissions from energy use grew by an average 5.4 percent per year (see Figure 1; for further detail, see Jotzo and Teng, 2014).

Figure 1. China's GDP, Energy and CO_2 Emissions, 2005–2013



Sources: Chinese official data come from the NBS (2013, 2014) and the *Xinhua Agency* (2013a, 2014). CO_2 levels to 2011 are from the International Energy Agency (IEA, 2013b), and authors' calculation for 2012–2013.
Notes: GDP refers to real GDP in RMB. Energy refers to total primary energy demand. CO_2, carbon dioxide.

The emissions intensity of the economy (the ratio of CO_2 emissions to GDP) declined steadily from 2005 to 2013, by a total of 29 percent (data sources as per footnote to Figure 1). Therefore, China is roughly on track to its target of reducing emissions intensity by 40 to 45 percent during 2005 to 2020 (Stern and Jotzo, 2010).

1. Drivers of Emissions Intensity Reductions

The overwhelming driver of the decline in emissions intensity has been steady improvement in the energy productivity of China's economy, as expressed in a falling energy intensity of GDP. Economy-wide energy productivity gains can arise both through improvements in technical efficiency (e.g. more efficient industrial plants and power plants and more energy efficient housing) and through changes in the composition of the economy (i.e. from heavy industry to higher-value manufacturing and services).

China has made very fast progress in energy productivity since the 1990s, with average annual reductions in energy intensity of almost 6 percent, associated with the industrial modernization of the 1990s (IEA, 2013b). The early 2000s saw only very modest progress, but the period from 2005 to 2013 saw strong reductions, averaging 3.8 percent per year (see footnote to Figure 1 for sources).

China has a long way to go in achieving the levels of energy productivity that currently prevail in developed countries. Measured at purchasing power parity, China's energy intensity is more than double that of Europe and Japan, and approximately 50 percent higher than that of the USA (IEA, 2013b). The differences are much larger when measuring GDP at exchange rates (see Table 1). Energy productivity in these advanced economies continues to improve, at typical rates of 1.5 to 2 percent per year. This means that China may continue to experience rapid improvements in energy productivity for a long time to come.

Table 1. Energy Intensity of GDP, Carbon Intensity of Energy and Emissions Intensity of GDP, Selected Economies, 2011

	Energy intensity: Energy/GDP (petajoules/US$bn)		Carbon intensity of energy: CO_2/energy (tCO_2/terajoule)	Emissions intensity: CO_2/GDP ($kgCO_2$/US$)	
	GDP PPP adjusted	GDP at exchange rates		GDP PPP adjusted	GDP at exchange rates
China	11.2	25.9	69	0.78	1.81
USA	6.9	6.9	58	0.40	0.40
Japan	4.9	4.2	61	0.30	0.26
EU	4.9	4.7	51	0.25	0.24
India	7.9	23.8	56	0.44	1.33

Source: IEA (2013b).
Notes: GDP in 2005 dollars. PPP, purchasing power parity.

The other factor contributing to reducing emissions intensity in China is the amount of carbon emitted per unit of energy, principally by reducing the share of coal, the most carbon intensive fuel, in favor of renewable energy, nuclear power and gas. The contribution of reductions in carbon intensity of China has been much more minor than that of energy productivity, averaging 0.5 percent per year during 2005–2013 (see footnote to Figure 1 for sources).

China's carbon intensity of energy supply is higher than that of the major advanced economies, principally because of the rich resource endowment of coal, and the dominance of coal in the energy system. However, said differences are less pronounced than for energy productivity. In addition, the carbon intensity of energy tends to change much more slowly over time, rarely by more than 1 percent per year (see Table 2). The reason lies in the persistence of energy supply infrastructure, consisting predominantly of long-lived assets, such as power stations. However, fast-growing economies, such as China, have the opportunity for faster reductions in carbon intensity, because a large amount of new energy infrastructure is added during any period.

Table 2. Rates of Change of Energy Intensity of GDP, Emissions Intensity of Energy, and Emissions Intensity of GDP, 1999–2011

	Average annual growth		
	Energy/GDP (%)	CO_2/Energy (%)	CO_2/GDP (%)
2000–2011			
China	−1.9	0.2	−1.7
USA	−1.9	−0.3	−2.2
Japan	−1.7	1.2	−0.6
EU	−1.7	−0.5	−2.2
India	−2.6	0.8	−1.8
1990–2000			
China	−5.8	0.9	−5.0
USA	−1.5	−0.1	−1.6
Japan	0.5	−0.6	−0.1
EU	−1.7	−0.8	−2.4
India	−1.6	1.3	−0.3

Source: IEA (2013a).
Note: GDP purchasing power parity adjusted.

Table 3. Illustrative Assumptions for How China Could Meet the 2020 Target and Achieve Falling CO_2 Emissions during the 2020s

	2005–2013 (actual)		2014–2020		2021–2030		2031–2040	
	Annual growth (%)	Index (2005 = 1) at 2013	Annual growth (%)	Index (2005 = 1) at 2020	Annual growth (%)	Index (2005 = 1) at 2030	Annual growth (%)	Index (2005 = 1) at 2040
Energy/GDP	−3.8[a]	0.74	−4.0[a]	0.55	−4.0[a]	0.37	−4.0[a]	0.24
CO_2/Energy	−0.5[a]	0.96	−1.0[a]	0.89	−1.5[a]	0.77	−1.5[a]	0.66
CO_2/GDP	−4.3	0.71	−5.0	0.49	−5.4	0.28	−5.4	0.16
GDP	10.1[a]	2.16	7.4[a]	3.55	5.8[a]	6.24	4.1[a]	9.33
Energy	6.0	1.59	3.1	1.97	1.6	2.30	−0.1	2.28
CO_2	5.4	1.52[a]	2.1	1.75[a]	0.0	1.76[a]	−1.6	1.51[a]

Sources: As per footnote to Figure 1.
Notes: [a]These figures are assumptions (see text).

2. A Scenario for Decarbonization

The road for China to keep reducing economy-wide emissions intensity and at some point also reduce overall carbon emissions probably lies in continued substantial improvements in energy productivity, coupled with accelerated reductions in the carbon intensity of the energy supply. In Table 3 we show an illustrative scenario that has China's carbon emissions peaking during the 2020s, returning to a level below the 2020 level by 2030, and back to around current levels by 2040.

The crucial parameter for China's absolute emissions is GDP growth. In the illustrative scenario we assume 7.4 percent per year for the reminder of the current decade, 5.8 percent during the 2020s and 4.1 percent during the 2030s (see Table 3).

For energy productivity, we assume a 4-percent reduction per year in energy intensity during the period of 2020–2040. This would reduce energy intensity by 25 percent relative to 2013 levels (45 percent relative to 2005), by half at 2030, and by two-thirds at 2040. Under these assumptions, China's energy productivity would match that of current US levels by the second half of the 2020s, and reach current European and Japanese levels in the second half of the 2030s. Given the rapid structural change in China's economy and the continued technological progress in energy efficiency, such a scenario is plausible.

For carbon intensity, we assume a 1-percent reduction per year for the remainder of the current decade, ramping up to 1.5 percent per year until 2040. This implies a continued and relatively rapid shift away from coal, substituting to renewables and nuclear power, as well as gas as a fuel in power production and industrial energy use. This assumption is ambitious in comparison to past changes in carbon intensity in China and internationally, but would seem achievable in light of continued investment in new energy infrastructure, and the desire to reduce coal use for other objectives, which will be discussed in Section IV.

Faster (slower) GDP growth would require greater (lesser) rates of energy productivity improvements and/or faster reductions in the carbon intensity of energy.

III. Opportunities for Decarbonization to Enhance Economic Growth

Over the past three decades, the Chinese Government has maintained a growth-first economic model for several reasons. First, the central government and local governments needed the economy to grow at all levels to alleviate poverty. Second, local governments, especially those in undeveloped regions of China (generally the western provinces) need high growth rates to generate sufficient revenue to finance their responsibilities, including social security, education, medical care, infrastructure development and environmental protection. Finally, local government officials are highly motivated to expand the scale of economy because their prospects for political promotion are closely linked to economic performance.

However, this development mode has received serious criticism in recent years because of the increasing recognition that economic growth, environmental protection and climate mitigation may conflict. The central government has increasingly placed emphasis on the quality of economic growth, not just the growth rate. The quality argument not only has an economic dimension (e.g. higher levels of capital and labor, and increased economic diversification), but also a social dimension (e.g. affecting inclusiveness and income distribution), as well as an environmental dimension (e.g. improved air and water quality and greenhouse gas emissions).

1. Opportunities for Productivity-raising, Carbon-cutting Reforms

Climate change mitigation offers opportunities to improve the productivity of capital and resources in China. Through policies and measures to foster structural change, improve energy efficiency and reduce future negative climate change impacts, China can enhance productivity and set its future economic growth on a more sustainable footing.

Over the past three decades of rapid growth, China's economy has been characterized by high savings and investment rates. The goal now is to rebalance the economy, with a higher consumption share in GDP and a lower savings/investment share, while maintaining economic growth at approximately 7 percent per year, still a fast rate of economic expansion but not as fast as during the preceding decade.

To maintain the growth rate at a relatively high level while reducing the investment rate at the same time, China needs to increase the productivity of its investment. One way in which investment productivity can be achieved is to shift the structure of the economy towards less capital-intensive sectors, for example, from industrial sectors to service sectors where investment has higher marginal productivity.

Another way to increase growth while lowering emissions is to raise the resource efficiency of capital investment, for example through energy saving technology. The structural change towards less capital-intensive sectors and the increase in the consumption share with a commensurate decrease in the investment share will substantially reduce the energy and carbon intensity of China's economy. The energy intensity of the service sector in China is only approximately one-third of the intensity of industrial sector.

As shown in Section II, China has considerable potential to improve its energy productivity. Improvement in technical energy efficiency, which is the amount of energy needed to produce a particular good or service, can also directly improve total factor productivity and contribute to GDP growth. Ward *et al*. (2012) find that a 1-percent improvement in energy intensity may contribute to a 1.1-percent increase in total factor productivity. China's policy to close small-scale and inefficient plants in the industry sector has also been assessed as having positive impacts on economic growth.

Fiscal policy reform associated with decarbonization can also benefit growth. Emissions reduction policies can be implemented using revenue raising instruments, for instance, a carbon tax or cap-and-trade schemes where some or all of the emissions permits are auctioned or sold to emitters. The resulting fiscal revenue can be used to lower existing taxes, and can result in higher efficiency of taxation if the existing taxes are more economically distorting than the taxation of emissions (double dividend hypothesis [see Goulder, 1995]). In a similar vein, carbon tax or permit revenue can be a source of required increases in fiscal revenue, avoiding the raising of rates of existing taxes.

Fiscal reform can also be used for targeted distributional change. For example, lower and middle income households can be left equally well off or better off as a result of changes in income tax rates and welfare payments when a carbon price is introduced, as was the case for Australia's carbon pricing mechanism (see Jotzo, 2012).

Finally, long-run capital and labor productivity may be affected negatively by the impacts of climate change. Examples are adverse impacts on health, damages to infrastructure, such as transport and housing, and disruptions to existing supply and production systems, including water distribution and agriculture.

2. Market Instruments and Market Reform

China's Government has flagged its intention to give a greater role to the market in China's economy. This approach of marketization is reflected in the climate change and energy policy arena. Many regulatory interventions to improve energy efficiency and reduce the carbon intensity of China's energy system are already in place.

The emerging direction is to rely more strongly on market instruments rather than the traditional command-and-control approach through direct regulation, administratively determined pricing and state-directed investment. Carbon pricing, through cap-and-trade (emissions trading) and/or an emissions tax (carbon tax) is seen as the backbone of cost-effective climate policy in any country (OECD, 2013).

China has established seven pilot emissions trading schemes, as laboratories in the lead-up to a planned national emissions trading scheme (Zhang *et al*., 2014). The expert community expects that a national emissions trading scheme, and perhaps also a carbon tax (probably at a lower price level), will be in place by the year 2020 (Jotzo *et al*., 2013).

However, market reform will be required for market instruments to be cost-effective, especially in the electricity sector (Baron *et al*., 2012; Jotzo, 2013).

On the supply side, changes in institutional arrangements and the incentive structure of power generators are needed in order to fully take account of future carbon costs in investment decisions for power plants. In a market system, plants with lower or zero emissions become more profitable as a result of carbon pricing, and the profit outlook affects investment decisions.

Furthermore, dispatch of existing power stations needs to be responsive to cost structures, including carbon costs. With flexible dispatch, emissions-intensive plants will tend to idle at times when power demand is low, and lower-emissions plants will be dispatched more often. The current system of regulated annual dispatch quotas for power stations does not facilitate the response to the carbon price.

On the demand side, a fully effective carbon pricing system allows the aggregate carbon costs to be passed through to consumers (both industry and households), increasing the incentives to reduce demand. In a competitive market, cost pass-through also means that aggregate industry profits are not greatly affected by carbon pricing, only the distribution of profits among different types of power stations.

3. Limitations of Conventional Modeling

Positive effects of emissions reductions policies on productivity are typically not fully captured in conventional economic modeling studies. Partial equilibrium modeling of climate change mitigation, usually by way of marginal abatement cost curves, does not take changes in productivity into account. Unless combined with specific estimates of beneficial impacts from mitigation, these analyses by their very nature present only costs not benefits.

Computable general equilibrium (CGE) models, the mainstay of economic analysis for mitigation policy assessment, do represent productivity, but they lack detailed information about differential productivity between sectors or activities, and typically assume that in the baseline economies follow an efficient pattern of investment and structural change. Thus, by default, a deviation from a model's base case (the hypothetical future scenario against which scenarios with emissions reductions are compared) will show up as a reduction in productivity and economic growth.

An exception is the existing structure of taxes, which is represented in CGE models, allowing the assessment of the welfare-raising potential of the fiscal aspects of mitigation policies. For China, a carbon tax has been shown to be potentially welfare increasing, in part depending on how the revenue is recycled (Cao, 2013). However, many CGE analyses of carbon pricing do not attempt to assess the welfare-enhancing potential of revenue recycling. Instead, modelers often opt for the assumption that carbon revenue is recycled in a lump-sum fashion, leaving existing taxes unchanged, which may result in overestimates of economic costs compared to fiscal reform scenarios.

Integrated assessment models (IAM) incorporate representation of climate change impacts and their feedback on the economy, including productivity impacts. They are essentially CGE models of the economy, run over long periods with assumptions about the economic impacts of climate change. They therefore allow, in principle, a cost–benefit analysis to be conducted based on expectation of future emissions and the costs and benefits of reducing them, and the physical effects of climate change and their impact on economies and society.

However, the cost of inaction on climate change and the benefit of avoided impact are seldom modeled in the national model due to lack of information. Most national-level CGE models only consider part of the cost–benefit problem, the cost associated with lowering consumption, but not the benefits of reducing climate risk. IAM typically exclude many impacts due to lack of information, or are likely to undervalue climate damages, for example, by focusing on mean expected impacts rather than modeling the full range of possible impacts and the risk of large-scale or compounding impacts (Weitzman, 2011). Uncertainty about future climate change impacts is a crucial factor in the assessment of future climate change impacts, as the possibility of catastrophic effects of climate change may overwhelm other aspects of a cost–benefit analysis (Weitzman, 2009).

IV. Benefits and Co-benefits from Mitigation

Decision-makers deal with more than one policy objective at a time. While climate change mitigation is a global and long-term objective, more immediate concerns should take priority. The multiple objectives are often in conflict with each other, or with the climate change mitigation objective. However, in the case of China, major benefits and co-benefits are aligned and reinforce the case for reducing greenhouse gas emissions, or, indeed, are a stronger driver of government policy than the motivation to reduce future climate change.

Co-benefits may include better air quality, which in China has now become the major driver of environmental policy. Co-benefits include improved energy security, energy access to poor people, more equitable distribution of income and wealth, and increased social stability. All these are in addition to the climate change benefits, which are often underestimated in conventional analysis.

1. Reducing the Risk of Climate Change

Traditional cost–benefit analysis, as applied in the economic modeling of climate change, usually considers uncertainty through expected utility theory. However, such treatment may not be appropriate for the climate problem because expected utility theory is designed for problems that have a known thin-tailed probability distribution (where the probability of outlying outcomes rapidly diminishes towards the extremes of the probability distribution). For climate change and associated impacts, the probability distribution is unknown, with a possibility of low probability but high impact (or catastrophic) effects in a relatively fat-tailed distribution. Therefore, the standard modeling exercises fail to take into account the implication of low-probability, high-impact outcomes.

It is important to regard climate mitigation as a risk management strategy for China to reduce its exposure to both climate risk and associated economic risk.

China is vulnerable to negative impacts of climate change. China's susceptibility to climate change can be inferred from its geography. The majority of the country's population, economy and urban built structure are located within 200 miles of the eastern coastline. China is classified, at number 49, as a "high risk" country according to the Climate Change Vulnerability Index (Maplecroft, 2011). Historically, the agrarian economy was both blessed and cursed by the East Asian monsoon, which brings rain for growing crops during the summer and blows wind across the continent in winter. However, with climate change, the East Asian monsoon may have significantly dampened and, therefore, aggravated the drought in northern China and flooding in the south. The glacial mountains in the west will eventually be affected so as to reduce the capacity to supply water for the rivers that have been watering the thirsty land and people for thousands of years. Thus, China's climate change strategy should primarily be considered as a risk management strategy for the nation's long-run development.

2. Air Pollution

The growth of fossil energy use has caused serious problems for the environment, which have drawn increasing attention in China (Yang *et al.*, 2013a,b). The persistent fog and haze in Beijing, Tianjin and Hebei Province, associated with particulate matter 2.5 (PM2.5), far exceeding the normal and acceptable levels, are mainly caused by coal combustion and vehicle exhaust emissions.

Air quality has become the number one issue for social instability in China. Because of the worst air pollution in recent years in China, air pollution has been become a cause for social unrest and political concern. Air pollution is contributing to millions of premature deaths a year and billions of dollars in environmental damage (see Table 4). Fine particles are a major source of air pollution. They can result from combustion and industrial processes, and are formed from the reactions of gaseous pollutants. If implemented properly, China's air-quality policies could have tremendous mitigation benefits, and help to protect human health. Exposure to pollutants such as airborne PM and ozone has been associated with increases in mortality due to associated disease. Outdoor PM pollution has been identified as the fourth-leading risk factor for death in China and suggested to be linked to 1.2 million premature deaths in 2010 (Lozano *et al.*, 2012).

Air pollutant emissions are also mainly connected to the increasing energy consumption. In 2010, coal consumed in China, including that burned in boilers and used in kilns, accounted for more than 90, 70 and 60 percent of national-wide emissions of SO_2, NOX and primary PM10, respectively (DRC and World Bank, 2013). Although China has made wide-ranging efforts to limit air pollution, such as requiring coal-fired power plants to install flue-gas desulphurization systems and strengthening vehicle-emissions standards, these measures are still not able to keep up with China's economic growth and fossil-fuel use.

Table 4. Environmental Depletion and Degradation in China

Environmental depletion and degradation as share of gross national income	2009	Greener value (2030)	Net improvement
Energy depletion	2.9	1.9	1.0
Mineral depletion	0.2	0.2	0.0
PM10 health damage	2.8	0.1	2.7
Air pollution material damage	0.5	0.1	0.4
Water pollution health damage	0.5	0.1	0.4
Soil nutrient depletion	1.0	0.1	0.9
Carbon dioxide damage	1.1	0.2	0.9
Total depletion and degradation	9.0	2.7	6.3

Source: DRC and World Bank (2013).

Air pollution damage is estimated at 2.8 percent of national income (see Table 4). This damage is closely linked to combustion of fossil fuel, especially coal. Thus, environmental benefits are a major component of the multiple benefits of climate actions. Especially in the energy sector, mitigation actions will have an important positive impact on the environment and air quality. A review of studies on monetized air quality benefit (Nemet *et al.*, 2010) found a range between US$27 and US$196 per ton CO_2 avoided for developing countries. Benefits of air pollution reductions on this basis outweigh most or all of the cost of reducing carbon dioxide emissions in many sectors of the economy.

3. Energy Security and Technology Leadership

Given the continued fast growth of China's economy, the manner in which China expands and transforms its energy system will have a global impact on energy systems. This relates to the scale and development of renewable energy, natural gas, nuclear power and also the international fuel market. The supply of renewable energy, natural gas and nuclear energy are not only constrained by resource availability, but also by the relative high cost of capital investment compared with that for coal-based technology.

Although China is heavily dependent on coal for its energy and industrial production, the government has recognized the attendant cost and risk associated with coal consumption and has begun to constrain the use of coal. The current coal-based energy system is characterized by low capital cost but high energy cost, and this is likely to continue in the future. High fuel cost shares mean that industries and households may suffer from price volatility.

China can improve its energy security by transforming to an energy system that is more efficient and where a greater share of electricity is produced from sources with zero or low fuel costs, namely renewables, such as wind and solar power as well as nuclear power. In this way, energy security improves both through reduced vulnerability to fuel price volatility and through reduced risk of disruptions to fuel supply systems. Increased energy security can also benefit growth.

With growing energy demand, China's energy supply has increasingly depended on foreign imports. It is expected that the proportion of imported oil will reach 70 percent and natural gas will reach 50 percent by 2020 (IEA, 2013a). High dependence on imports makes energy security an important factor. In the current situation, supplies are secure. However, emergencies in some regions and geopolitical factors may cause a temporary shortage of supply and price fluctuations, which presents a certain risk for the stable operation of economy. Increasing the use of coal could reduce the dependence on foreign energy, but it runs counter the air pollution and climate change objectives.

As argued in the *Global Energy Assessment* (Johansson *et al*., 2012), more stringent global climate change policy results in increasing energy security. Thus, energy security can be considered an important co-benefit of stringent climate policy.

Deployment of new energy technologies at a large scale, as is possible through the domestic market in China, can reduce future investment costs through economies of scale and accelerating technological refinement and learning-by-doing in manufacturing. Solar panels and (to a lesser extent) wind turbines have seen dramatic reductions in manufacturing costs in recent years, as a corollary of the expansion in Chinese plants. This has improved energy investment efficiency not only for China but also for the world. Significant further cost reductions are likely with continued increases in manufacturing volumes.

Innovation in new and renewable technology also can contribute to the growth of China's economy in other aspects. Development of the renewable energy industry is in line with China's development strategy to support "strategic emerging industries," including energy efficiency, environment technologies, new energy, new energy vehicles, biotechnology and new materials. Cost reductions in China-based manufacturing of critical components of new technologies will help China to position itself in the upstream chain of global innovation. China has become the lead exporter of solar photovoltaics and wind turbines and also takes the leader in battery and LED lighting industries.

V. Conclusion

With an average growth rate of around 7 percent per year, China may double its economic output within a decade. With the resource-intensive mode of economic growth that has dominated to date, such growth would pose unacceptable burdens on energy demand and the local environment (including air quality), and increase greenhouse gases emission. Therefore, there is a need for a paradigm shift of the development model of the Chinese economy, a model that builds on synergy of economic efficiency, social equity, energy security and environmental sustainability.

Climate policy should be regarded as a risk management strategy for China. Reductions in emissions can be achieved through changes in economic structure, together with improving energy efficiency and transformation towards a low carbon energy supply. In this way, climate change risks can be reduced while meeting other policy objectives, including better air quality and improved energy security, while also meeting the primary goals of economic growth and development.

Such a new paradigm needs to start from a rethink of the relationship between climate change and economic growth. China is on the way towards a model of growth that relies more on consumption and less on investment. To maintain a high growth rate it is necessary to improve investment productivity.

Investment productivity can, among other avenues, be achieved through structural change towards higher-value manufacturing industries and services that can obtain greater productivity gains, and through technical improvements, including increased energy efficiency. Both contribute greatly to the reduction of energy intensity of the economy, and to lower emissions of CO_2 per unit of GDP. Such a growth model is more robust in the face of environmental and resource constraints, and also to the risk of energy price fluctuation.

To make this transition requires changes in the mindset of cadres, in the guiding ideology for Chinese development and in the concept of economic growth. The central government should make a conscious trade-off between GDP growth that depends on resource industries, and the costs incurred by such resource use and the resulting environmental damage. Development in the central and western regions needs to be redesigned and readjusted by drawing more attention to climate change, and to pursuing economic growth alongside improved environmental quality.

At its 18th Congress, the Chinese Communist Party, for the first time, made ecological civilization a central theme of its constitution (Xi, 2012). The concept of ecological civilization focuses on the harmonious relationship between man and nature. A political consensus built among the top leaders of the party and the nation is to transform the economic development model from one that emphasizes growth to a new one that combines economic efficiency, social equity and environmental sustainability. Climate change must be a key element of the new economic development model.

The conventional viewpoint, by contrast, sees a high-carbon trajectory as the default and interprets deviations from it as welfare-decreasing. This can be true, and will often be true if the benefits from climate change mitigation are undervalued and co-benefits ignored. However, often it will not be true, and steps towards a lower carbon economy will pay off.

To better identify the true costs and benefits of actions to reduce carbon emissions, the economics profession needs to take a fresh and unbiased look at the theoretical approaches that are favored, the tools that are employed, the data that are used, and the assumptions that are made.

Economic analysis underpinning China's climate policy should not be centered on the cost of emissions reductions in terms of foregone GDP growth without reference to the quality of growth and its environmental and social dimensions. Rather, climate policy needs to be seen as a driver of sustainable economic growth, as a tool to manage climate risk and an approach to realize multiple benefit. An inclusive cost–benefit analysis should not only be embedded in project appraisal, but also in the public investment and decision-making process, to ensure that decisions regarding climate change are in line with China's broader interest.

Studies that look at the broader impacts of climate policy, many of which are positive, as well as the whole suite of impacts of climate change, most of which are negative, are necessary for a more comprehensive cost–benefit analysis. Scientific research is increasingly recognizing the diversity of effects of climate change mitigation on longer-term economic development. However, there is still a long way to go to integrate a broader range of effects in the economic models that are typically used for climate change policy analysis.

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