China: Economic and GHG emissions Outlook to 2050

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1 Introduction

The New Climate Economy project to identify the opportunities for strengthening economic growth and climate performance has a major Work Area for China given the large contribution to the world economy and greenhouse gas emissions by China. This Work Area recognizes the intimate link between CO2 emissions and local pollution that is of great concern in China and calls for scenario analysis of economic growth, energy consumption, air quality and greenhouse gas (GHG) emissions. The Tsinghua University research group responsible for this Work Area has organized a research framework consisting of the following elements: a) economics, b) energy systems, c) air pollutant emissions and GHG, d) atmospheric science and air quality.

It is often useful to break down the factors driving energy consumption growth to (a) growth in aggregate output (GDP), (b) changes in the industry composition of aggregate output, and (c) changes in technology used to make industry output. By composition of output (or structure of the economy) we mean the relative sizes of the different industries; agriculture, food manufacturing, iron and steel, communications, etc. Changes among more finely classified industries would also affect energy consumption, e.g., animal production versus crop production, or air transportation versus rail transportation. "Technology" refers to all aspects of production methods including capital intensity, choice of energy type, scale of operation, degree of outsourcing, etc.

The above three economic factors driving total energy use and the mix of energy, in turn, are affected by domestic policies, as well as external factors such as world fossil fuel prices. Domestic policies would, in particular, include economic and energy policies, as well as trade policies. Total energy use and the mix of fuels, in turn, drive pollutant emissions and environmental quality Air quality, of course, is also determined by domestic environmental policies as well as depositions from other countries.

Economic performance is thus the first point for the analysis of carbon emissions and air quality, and the sustainability of current economic growth patterns is of great concern for many world leaders, including the Chinese government. Will the world run out of mineral resources such as iron and fossil fuels, or run out of natural resources such as water, arable land, forests and fisheries, or will the environment be so degraded as to be fatal to human life? As a result of such concerns many governments and global institutions such as the United Nations and the World Bank, have begun to focus on "green growth."

While there is no consensus definition of green growth, it is generally thought to be economic growth that is environmentally sustainable, and which is an essential component of sustainable development[1]. The World Bank says that green growth "can be thought of as economic growth that is environmentally sustainable, … [and] that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts, and resilient in that it accounts for natural hazards and the role of environmental management and natural capital in preventing physical disasters" (World Bank 2012, page 30). UNEP (2011) says that "a green economy is low carbon, resource efficient, and socially inclusive," and World Bank (2012) also recognizes that low-carbon development is part of the green growth agenda.

There are two well-known interlinked aspects to this relation between low-carbon development and green growth. The burning of fossil fuels generates particulate matter, sulfur dioxide, NOx and other emissions that make the air hazardous for human health, and it also generates carbon dioxide, a greenhouse gas that raises climate change risks. How do these aspects affect economic performance? As explained in Ho and Wang (2014), it is helpful to think of economic output as a function of physical capital, labor, natural capital and "technology." Natural capital would include mineral resources, forests, fisheries, clean air, etc. A green growth strategy would affect all four of these inputs.

A low-carbon development path which reduces air pollution would reduce the number of sick or dead workers, and reduce the damages to physical capital such as buildings and equipment. It also reduces damages to natural capital such as the impact of acid rain of fisheries. That is, lower pollution leads to lower repair costs and higher economic output. Policies such as energy efficiency standards would affect "technology", i.e., change the production methods, types of equipment and types of fuel. There is a debate about whether these innovations in technology are cost effective; the Porter hypothesis suggest that the changes triggered by government energy policies reduce both energy consumption and total production costs. While

[1] Ho and Wang (2014) discuss the origin and interpretations of the green growth concept and its relation to sustainable development. The broader concept of sustainable development was defined by the Brundtland Report in 1987 as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." It includes three pillars – economic development, environmental protection and meeting the needs of the poor.

the evidence of this win-win outcome is unclear, it is clear that policies do affect technology choices, and thus emissions of local pollutants and CO2.

The discussion in the green growth literature points to many policy instruments to achieve a low-carbon path. These include carbon prices, energy efficiency standards, renewable portfolio standards, subsidies for research and development, and reducing market failures. We do not discuss these policies here but note that environmental protection policies have a complicated relation to GHG targets. A policy to reduce coal use to reduce air pollution would reduce CO2. A policy to require flue-gas desulfurization equipment would require more electricity and thus generate more CO2. A coherent green growth strategy should thus take into account all these aspects of energy use and emissions. A comprehensive analysis of policy should thus also take these multiple channels of interaction into account.

In this report we consider several economic growth and policy scenarios in our analysis of energy consumption and emissions. We begin by discussing the economy – the outlook for economic growth and changes in the structure of the economy. We describe how policies, consumer preferences and external conditions, affect economic growth, industry structure and GHG emissions over the period 2012-2050.

We are thus interested in fairly long-term projections, forecasts that involve a great deal of uncertainty given the long horizon. There are vigorous debates, inside and outside China, about both near-term and long-term prospects for economic growth; ranging from the optimistic outlook of "8% growth for many more years" to "prolonged middle income trap" to "renewed global economic crisis." We discuss these debates in Section 3 after reviewing the sources of growth in China in Section 2. Given this lack of a clear consensus forecast, the Tsinghua research group has decided to do a scenario analysis with three distinct base cases for economic growth. In our Central case, GDP growth decelerates to 4.6% per year during 2020-2030 from the current 7 to 8% rate; in the Optimistic case it slows only to 5.6%; and in the Pessimistic case there is a sharp deceleration to 3.6%. However, even in the Pessimistic case, China escapes the middle-income trap given the current definition of high-income as elaborated in Section 3.

In the sections below we describe the assumptions regarding population growth, productivity growth, savings rates, changes in the structure of consumer and industry demand, and changes in other external factors that generate these three growth scenarios. The growth projections are made using a multi-sector economic growth model of China that has been used to analyze environmental policy (Cao, Ho and Jorgenson 2013).

As noted, economic activity and GHG emissions are directly affected by all types of public policies. In these base cases we assume that energy and carbon control policies are those which will achieve the carbon intensity target announced by the government in late 2009 at the United Nations Framework Convention on Climate Change (UNFCCC) meeting. That is, achieving a 40-45% reduction in the carbon intensity (carbon emissions per unit GDP) by 2020 compared to the 2005 level. We also assume that the environmental policies in the 12th Five-year plan are continued, these include the targets for sulfur dioxide.

We then examine a low-carbon policy that targets total carbon emissions from fossil fuels and cement production so that they peak around 2030. At that point CO2 emissions are 13% lower than in the no-policy base case. While this is a relatively ambitious target we believe it is a reasonable case to consider. As a comparison, the "450 Scenario" of the International Energy Agency's *Redrawing the Energy-Climate Map* (IEA 2013) requires a 50% reduction in CO2 emissions by 2030 compared to our base case. Such a scenario requires extremely high carbon prices and large changes in the energy system. Our policy only requires a tax of 23 yuan per ton of CO2 in 2030, gradually rising to 68 yuan per ton. We estimate that the cost of such a policy to be 0.5-0.8 percent of GDP.

2. The sources of past growth in China

Before we discuss the projections of future economic growth, it would be useful to review the drivers of growth in China since the reforms started in 1978. Even in discussions of the past, there are debates about the main factors driving growth. While there is a consensus that reform policies and the opening up to the rest of the world were key general factors for China's rapid growth since 1978, there is disagreement about the details. We do not review the entire debate here but focus on a simpler question – what are the proximate sources of growth in the post-1978 period?

The simplest workhorse model of economic growth expresses aggregate output (or GDP) as a function of capital, labor, and "total factor productivity (TFP)", or $Y_t = f(K_t, L_t, A_t)$. Capital includes structures, equipment, land and even intangible assets such as patents and software. The TFP term is often referred to as the productivity residual, or what we cannot explain specifically about output growth. We think of it as encompassing factors such as technological progress, reallocation of capital and labor from one sector to another, network externalities, unmeasured public capital or reduction of market failures over time. The exercise to decompose output growth into capital input growth, labor input growth, TFP and other specific factors is called "growth accounting" or accounting for the sources of growth.

This accounting of aggregate growth is commonly done since it is the easiest first step, however, this simple abstraction leaves many important factors out. Modern economies produce many different goods and services, and for each product, different companies use different technologies to make it. GDP is often calculated as a weighted sum of the commodities in final demand[2], or equivalently, as the weighted sum of the value added of each sector[3]. The changing composition of final demand (e.g. more consumption and less investment), or a change in the composition of commodities making up final demand, or a change in the prices of the commodities, given the same total number of workers and machines, will change real GDP. Equivalently, a change in the industry structure, i.e. a change in the proportion of workers and capital in the different sectors, will change GDP. A more detailed accounting of the sources of growth will thus include the impact of these changes in addition to the capital, labor and TFP identified in the simple aggregate accounting.

In the measurement of labor input some studies would simply use the number of workers while others distinguish between the types of workers and use a measure of labor input that takes the quality, or human capital, into account. Similarly, some studies use the value of total capital stock to measure capital input, while others recognize that different assets have different useful lifetimes. The studies using the simpler measures will usually estimate higher rates of TFP growth since the improvement in labor quality will be part of this residual.

Capital, labor and TFP are the proximate sources of growth, one needs a theory of why capital and labor grew at the rates they did, and a whole academic industry is built around trying to explain the TFP residual in terms of the specific factors noted above. We defer the discussions of these theories and begin by first reporting the growth accounting results for the simplest

[2] Final demand is composed of Consumption, Government consumption, Investment, Exports less Imports, and it is to be distinguished from "intermediate demand." Intermediate demand refers to commodities purchased by enterprises to produce final goods, for example, the steel used to make cars, or the fuel to run the train. GDP only counts the value of cars produced and does not double count the steel embodied in them.

[3] The value added of, say, the automobile manufacturing industry, is the value of automobiles produced less the purchases of intermediate inputs. Value added has 3 components, the part due to labor, the part due to capital and indirect business taxes.

aggregate model like that specified above in subsection (a). We next report, in (b), the growth accounts that take into account the detailed industry and commodity structure of the economy.

a) Aggregate growth accounting

The results from seven studies of the sources of growth using aggregate data are summarized in Table 1. Chow and Li (2002) find a positive TFP growth of 3.0% in the post-reform period, 1978-98, with capital input growth contributing 5.1 percentage points and labor input contributing 1.2 points. That is, of the GDP growth of 9.35% during this period, total factor productivity accounted for 32% and capital for 55%.

Wang and Yao (2001), in a World Bank study, takes into account labor quality by including data on the number of schooling years. In their central estimate for the 1978-99 period reported in Table 1, they estimated a TFP growth rate of 2.3% per year; of the 9.7% growth rate of GDP, capital contributed 4.7 percentage points and quality-adjusted labor contributed 2.7 points. Using other assumptions about labor income shares, they estimate TFP growth to be the 1.92 to 2.98 range. Islam, Dai and Sakamoto (2006) also adjust for labor quality and estimate that TFP growth to be 2.95% per year during 1978-2002. They also report estimates of TFP for sub-periods which showed a volatile behavior; 5.7% (1978-84), 1.2% (1984-91) and 3.0% (1991-2002). Lee and Hong (2010) use data from a cross section of countries and make a simple adjustment for human capital. They estimate that for China, over the 1981-2007 period, out of the 9.4% GDP growth rate, capital contributed 4.4 points, labor 0.9 points and TFP 4.1 points.

There are many debates about the quality of the official National Accounts data and a number of studies provide alternative estimates of real GDP growth[4]. Perkins and Rawski (2008) accept the official GDP estimates after 1995 but revise them slightly for the period before 1995. They also adjust for labor quality and estimate aggregate TFP growth at 3.8 percent between 1978 and 2005 and suggest that TFP accounts for 40% of overall growth in these three decades of economic reform. Cao et al. (2009) also adjust the official GDP estimates and put GDP growth at 8.9% for 1982-2000, of this capital input contributed 4.6 percentage points, labor input 1.8 points and TFP growth 2.5 points. The capital input calculation in Cao et al. includes a composition adjustment to the stock of capital.

[4] See, for example, Ren (1997), Young (2003) and Maddison and Wu (2008).

Brandt and Zhu (2010) also revise the official data and estimate a lower growth of capital input compared to the official investment data. For the period reform period until the world financial crisis, 1978-2007, the estimate that TFP growth contributed 3.9 percentage points out of an adjusted GDP growth of 9.3% per year[5]. They do not include any adjustment for human capital, so the TFP of 3.9% includes the contribution of human capital accumulation. They also estimated the contribution of the reallocation of factors from agriculture to other sectors and also noted the big difference in performance between the state and non-state sectors.

Finally, World Bank and DRC (2013) does not provide a detail growth accounting but does report that labor productivity was growing at 8.9% per year during 1995-2010, and this forms the basis of their projections for future growth.

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[5] Brandt and Zhu (2010) only reports output per worker (their Table 1). They also report the growth of labor input and our estimates here are based on our adjustments of their output and capital per worker estimates.

Table 1. Sources of growth from aggregate studies

	Chow & Li (2002)	WB: Wang & Yao (2001)	Cao et al. (2009)	Islam et al. (2006)	Perkins & Rawski (2008)	ADB: Lee & Hong (2010)	Brandt & Zhu (2010)
Period	1978-1998	1978-1999	1982-2000	1991-2002	1978-2005	1981-2007	1978-2007
Output variable	GDP	GDP	Adj. GDP	GDP	Adj. GDP	GDP	Adj. GDP
Output growth (%)	9.35	9.72	8.91	9.37	9.5	9.35	9.28
Capital contribution	5.10	4.69	4.57	4.27	4.2	4.42	4.51
Labor contribution	1.23	2.70	1.83	2.15	1.5	0.85	0.85
Total factor productivity (%)	3.03	2.32	2.51	2.95	3.8	4.07	3.92

b) Sources of growth at the industry level

The above studies use data on GDP and total capital and labor input and are easier to do and thus more numerous. As we noted, such aggregate studies cannot capture the impact of the changing composition of commodities and the reallocation of workers from agriculture to manufacturing and services, and cannot distinguish the very different rates of productivity growth in the different sectors. Some studies thus create growth accounts at the industry level; they estimate output, capital, labor and intermediate inputs for each industry and calculate the TFP residual from an industry output function, $Q_{jt} = f(K_{jt}, L_{jt}, \mathrm{M}_{jt}, \mathrm{tfp}_{jt})$ for each industry *j*. Studies at the industry level have shown that different industries have very different performances and that productivity growth is dominated by a few industries. GDP growth itself is dominated by the rapidly growing sectors with a falling contribution from shrinking sectors. For the United States, Jorgenson, Ho and Samuels (2011) estimated that the tiny Information Technology producing sector, which is only 3 percent of GDP, contributed more than half of the total factor productivity growth of the whole economy for 1995-2007. It also contributed to 18 percent of GDP growth during the economic boom of 1995-2000[6].

The accounting of the sources of GDP growth using industry accounts becomes more complicated as explained in Cao et al. (2009) study of 33 industries for the 1982-2000 period. GDP is the aggregation over all industries of industry value added, and aggregate TFP growth that was discussed in section (a) above now consists of three components: (a) the TFP growth at the industry level, summed over all industries, (b) reallocation of capital across industries, (c) reallocation of labor. Table 2 reproduces the results, of the 8.9% growth in aggregated industry value added, aggregate TFP contributed 2.5 percentage points. Of this 2.5% growth in aggregate TFP, the weighted sum over industry TFP contributed 2.70 points, the reallocation of capital and labor -0.19 points[7]. Of the sum over industry TFP of 2.70 percentage points, more than two-thirds come from the secondary industry (manufacturing, mining and utilities), while the tertiary

[6] The industrial productivity records of European countries are described in Mas and Stehrer (2012) and show a similarly large range of performance across industries.

[7] The relation between industry TFP and aggregate TFP is explained in Jorgenson, Ho and Stiroh (2005, Chapter 8). Since there are flows of intermediate inputs from one industry to another, the TFP growth of one benefits all industries. The weighted sum of industry TFP's in Table 2 involve weights that add up to more than 1; weights that involve output shares and value-added shares. In an economic system where the typical share of value-added in gross output at the industry level is 0.4, the aggregate TFP growth would be 3.75% when industry TFP growth averages 1.5%.

sector made a negative contribution. That is, in the 1982-2000 period, total factor productivity growth in services is negative.

The most important industries among the 33 sectors identified contributing positively to TFP growth in China are Agriculture, Machinery, Electrical Machinery and Trade industries. These are the sectors which are large and have higher TFP growth. The most negative contributions to aggregate TFP are from Oil & gas mining, Finance and Private services.

Table 2. Sources of growth by aggregating over industries, Cao et al. (2009)

	1982-2000		
Value added aggregating over industry (% p.a.)	8.91		
Capital contribution	4.57		
Labor contribution	1.83		
Aggregate TFP	2.51		
Contribution to Aggregate TFP			
Weighted sectoral TFP		2.70	
Primary Industry			0.91
Secondary Industry			2.10
Tertiary Industry			-0.31
Reallocation of capital		-0.17	
Reallocation of labor		-0.02	

There are very few comprehensive studies of productivity at the industry level given the difficulty in collecting such industry data. Wu (2007) considers only the secondary sector and estimated TFP growth in 22 mining, manufacturing and utility industries over the 1980-2005 period. He also finds a wide range of industry TFP estimates ranging from 14.9% per year in Metal Mining, to 5.2% in Textiles, and to -6.7% in Petroleum Refining & Coal Products for the period 1993-2005. Averaging over all the manufacturing industries the TFP growth was 0.1% for 1980-1993 and 7.2% for 1993-2005.

Chen, Jefferson and Zhang (2011) first survey the literature on industry estimates, most of which cover only manufacturing, or secondary industry, only. Some use firm level data while some use only value added data excluding intermediate inputs. Their survey shows a very large range of estimates of the TFP of the secondary industry, from -1.1% (1992-96) to 17% (2000-05). Chen et al. (2011) also estimate the TFP of the secondary sector using firm level data, and averaging over all firms for the period 1981-2008, they estimate that of the 12.5% growth in industrial value added, aggregate TFP growth contributed 6.7 percentage points. This aggregate TFP consist of a big positive technical improvement of leading firms but a negative contribution from lagging firms, it also includes a positive reallocation effect from the expansion of more productive firms.

c) Discussion

We draw the following conclusions from the above growth accounting exercises. One, the growth of capital input from investment is the major source of growth in China in the post-1978 period. Two, total factor productivity growth played a significant role in GDP growth, in the range of 2 to 4 percentage points of the 9 percent or so GDP growth. This TFP growth was, however, quite volatile even at the aggregate level. The growth of labor input, even accounting for improvements in human capital, played a more modest role, about 1 to 2 percentage points. Three, aggregate productivity growth comes from a very wide range of TFP growth at the industry level, with some stellar industries showing rapid TFP improvement and some showing negative growth including the very large tertiary (services) sector. Fourth, the reallocation effect on GDP growth is ambiguous, within each sector there may be a positive effect of reallocating from less productive to more advanced enterprises, but the effect of reallocation of capital and labor between industries (at the 2-digit classification in Cao et al. 2009) may be small or negative.

It is widely expected that the structure of the economy will continue to change with a decreasing share of workers and factors devoted to agriculture and a rising share to services, and within manufacturing a movement from low-skill and low-wage industries to higher-wage ones. Given the lower TFP growth in services compared to agriculture (both in the Chinese experience discussed here, and in the experience in other countries described in Mas and Stehrer 2012) we can expect a negative contribution from this aspect of structural change. The movement from low-skill but high TFP growth industries such as Apparel towards high-skill aerospace and pharmaceuticals industries would have a more uncertain impact on aggregate TFP growth.

The above are the proximate causes of growth, one needs a theory to explain these observations. We need to ask if the allocation of capital was efficient and if policy was properly supportive of innovation that drives part of TFP growth. These questions are part of the debate about the future of Chinese economic growth; will reform improve the allocation of output between consumption and investment, will reform improve the allocation of capital, and will reform lead to innovation and productivity growth? In the next section we discuss this debate.

3. The debate about growth in developing countries and forecasts for China

The rapid rate of China's economic growth has been much noted, but we should also point out the relative stability of this growth, according to the official statistics. While there was a sharp slowdown in the crisis of 1989-90, annual GDP growth was between 7.6% and 14.2% during 1992-2013[8]. Over the period 1995-2007, up to the eve of the Global Financial Crisis, it averaged 9.4% per year, and decelerated to 8.6% during 2007-2013. In the most recent two years, 2012 and 2013, GDP growth was 7.7%, the slowest since the aftermath of the 1997 Asian Financial Crisis.

This slowdown in growth in China has engendered much debate about whether it is merely a cyclical phenomenon due to the slow global recovery from the Great Recession, or it is part of a secular trend. This debate about Chinese growth is part of the larger discussion about the slowdown from rapid economic growth of developing countries. The World Bank volume, *An East Asian Renaissance* (Gill and Kharas 2007), has popularized the term "middle-income trap" which refers to the situation where countries are unable to sustain high growth rates that transformed them from poor to middle-income countries, remaining as middle-income for decades without being obviously able to join the high-income club soon. This is a topic that seems to be not only on the minds of economists but of almost every policy maker or analyst interested in China[9].

Gill and Kharas (2007) noted that a growth strategy based only on investment (capital accumulation) will deliver steadily poorer results with the natural decline in the marginal productivity of capital. That is, when a country is really poor, a unit of investment delivers a very high addition to GDP, but when there is much more capital after two or three decades of investment, the additional unit of investment gives a much lower return. They argue that "Latin America and the Middle East are examples of middle-income regions that, for decades, have

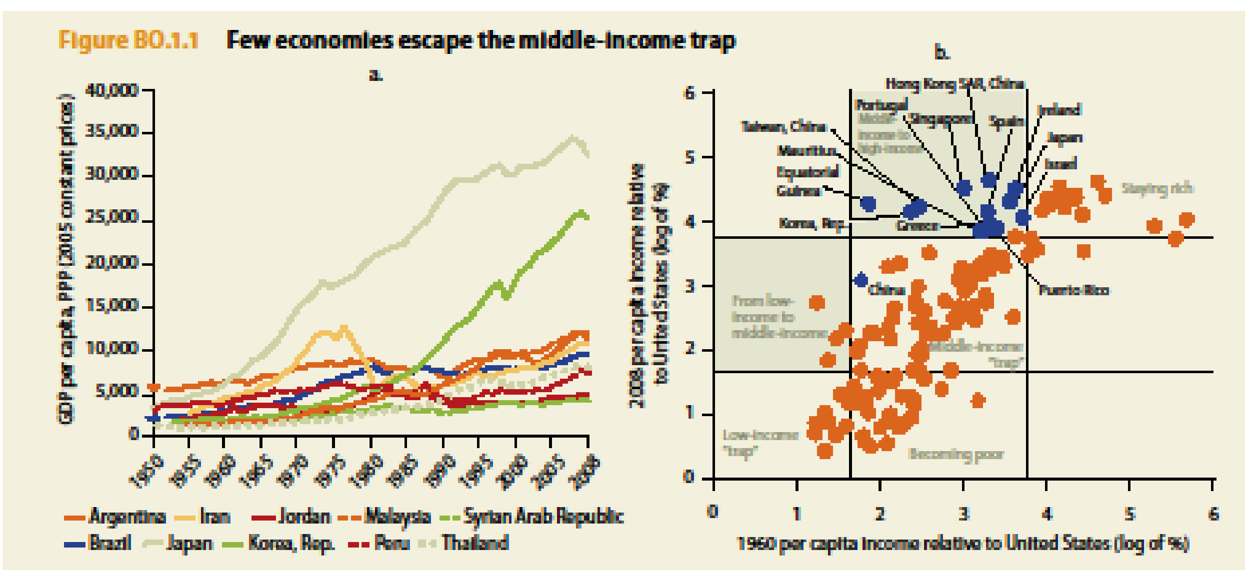
[8] Data for the National Accounts are given in the China Statistical Yearbook 2013 for 1978-2012, and the National Bureau of Statistics webpage give updates for 2013; see http://data.stats.gov.cn

[9] Eichengreen et al (2012) noted that a Google search in 2012 for the term "middle-income trap" identifies nearly 400,000 pages of references. A search in July 2014 of the more limited phrase "middle-income trap China" generated 401,000 results.

been unable to escape this trap." They go on to argue that the successes in East Asia (Korea, Taiwan, Hong Kong, Singapore) may be explained by their shifting "toward growth that is founded on economies of scale," that is, they benefitted from being major producers of electronics, computers and communications which exhibit sizable economies of scale, and from being able to learn the new technologies by being close to the technology innovators in Japan and the U.S.

While this is not the place to review the large literature on the comparison of East Asian development with the rest of the developing world[10], we briefly describe this middle-income trap phenomenon given the intense interest in it by Chinese policymakers and analysts. The report by World Bank and DRC (2013), *China 2030*, contains a comprehensive discussion of the sources of growth in China in the past and the challenges of developing a new growth strategy for the future. It gives a good summary of the middle-income trap and Figure 1 below reproduces a Figure from it titled "Few economies escape the middle-income trap" (World Bank and DRC 2013, page 12).

Figure 1. The middle-income trap. Reproduced from World Bank and DRC (2013).



Source: Heston, Summers, and Aten 2011.
Note: PPP = purchasing power parity.

Source: Maddison database.

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[10] See, for example, Elson (2006).

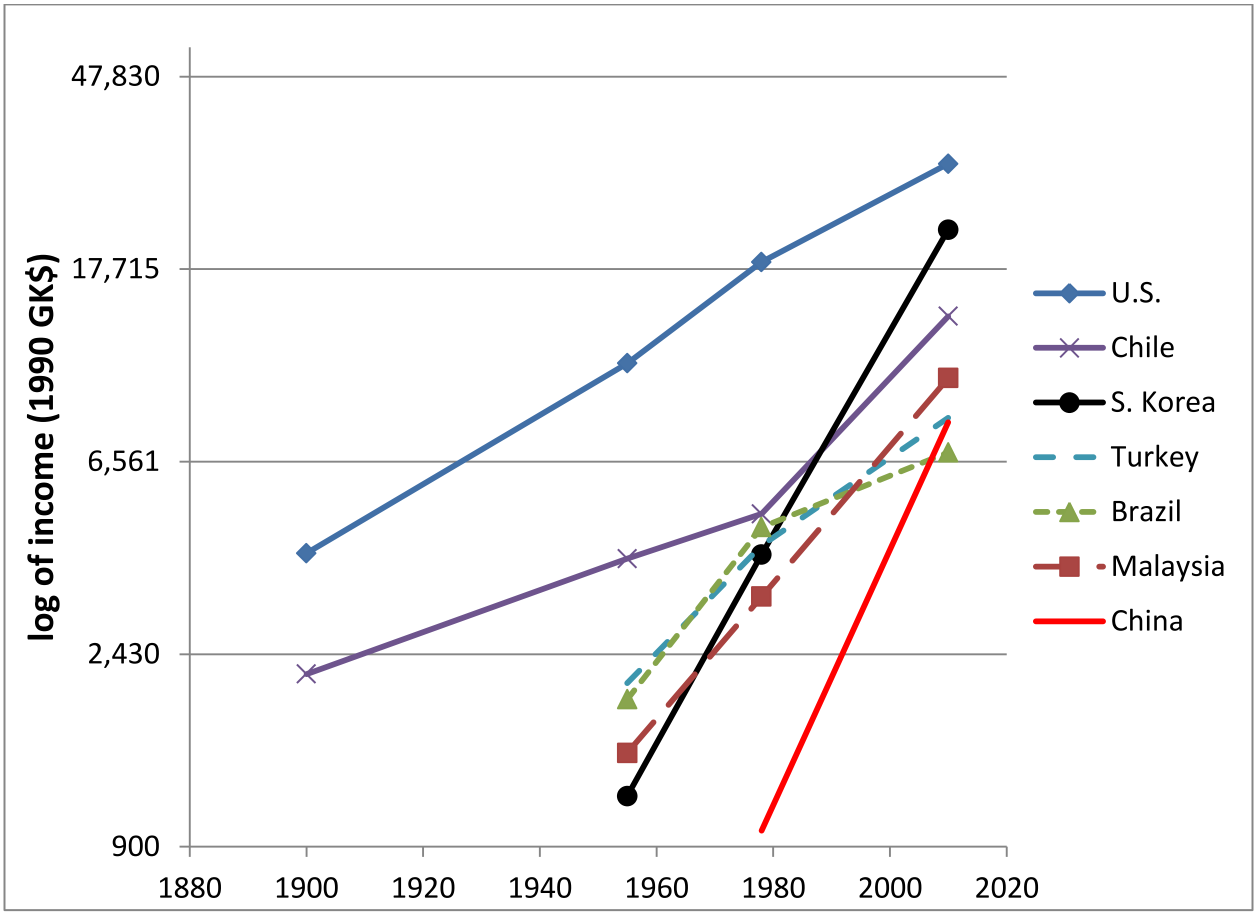
In the right panel of Figure 1 the relative income in 2008 is plotted against relative income in 1960. (The incomes are relative to the U.S., and the axes are in logs, so the U.S. is represented by ln(100%)=4.6. China is represented by a blue diamond, with a relative income in 1960 of 5.84% and 21.5% in 2008. Ln(5.84)=1.8 and ln(21.5)=3.1). The countries marked by blue circles are those few which managed to transit from middle incomes in 1960 to high incomes in 2008; the majority of the dots are in the center box which represent the middle-income countries of 1960 remaining as middle-income in 2008[11]. The report stated that "of 101 middle-income economies in 1960 only 13 became high income by 2008" (World Bank and DRC 2013, p 12). We should emphasize that remaining in the middle-income group does not mean that there is no progress. If we draw a 45° line in the center box, then countries above the line will have closed the gap with the U.S. between 1960 and 2008, and some of them are close to joining the high-income group. Countries below the 45° line are falling further behind the U.S. The bottom boxes represent countries that remained low-income, or fell from middle-income status to low-income.

Figure 2 compares the changes in per-capita income of six countries with that of China (red line) using the same Maddison database for 1900, 1955, 1978, 2010[12]. Chile and South Korea are the countries that managed to reach high-income status by 2013, Turkey, Brazil and Malaysia are examples of those that have not escaped the middle-income trap; these countries had incomes higher than South Korea in 1955 as shown in Figure 2 but Turkey and Brazil had significant slowdowns.

[11] The World Bank currently classifies a country with per capita income in 2013 in the range $1036-$4085 as lower middle-income, and in the range $4086-$12615 as upper middle-income (using their *Atlas* exchange rates), see http://data.worldbank.org/about/country-and-lending-groups . By this definition, China's income in 2013 is $6560, and U.S.'s is $53,670. The data for Figure 1is however, taken from the Maddison database which gives a different estimate of PPP-adjusted incomes from the World Bank database. The data given at http://data.worldbank.org/country/china gives $7431 as the PPP-adjusted income for China in 2008, which is 15.4% of the U.S. income in 2008 (all in current $). The Maddison database is given at http://www.ggdc.net/maddison/maddison-project/data.htm .

[12] 1955 is after the Korean War, 1978 is the start of the Chinese economic reforms, and 2010 is the last year of this Maddison database.

Figure 2. Rise in Per-capita Income of Selected Countries



The *China 2030* report suggested that these middle-income countries fail to become rich because, when faced with sharp decelerations, they "have been unsuccessful in addressing the root structural cause of the slowdown". They also suggest that China can avoid this middle-income trap by finding new growth drivers including "increased efficiency in input use, higher human capital investments, increased innovation, and a shift to high-value services". They estimate that such actions should result in growth between 6 and 7 percent for the next two decades. They, however, also warn of the many risks to continuing rapid growth, including high income inequality, low consumption, barriers to labor mobility, social tensions, external imbalances and environmental and resource constraints.

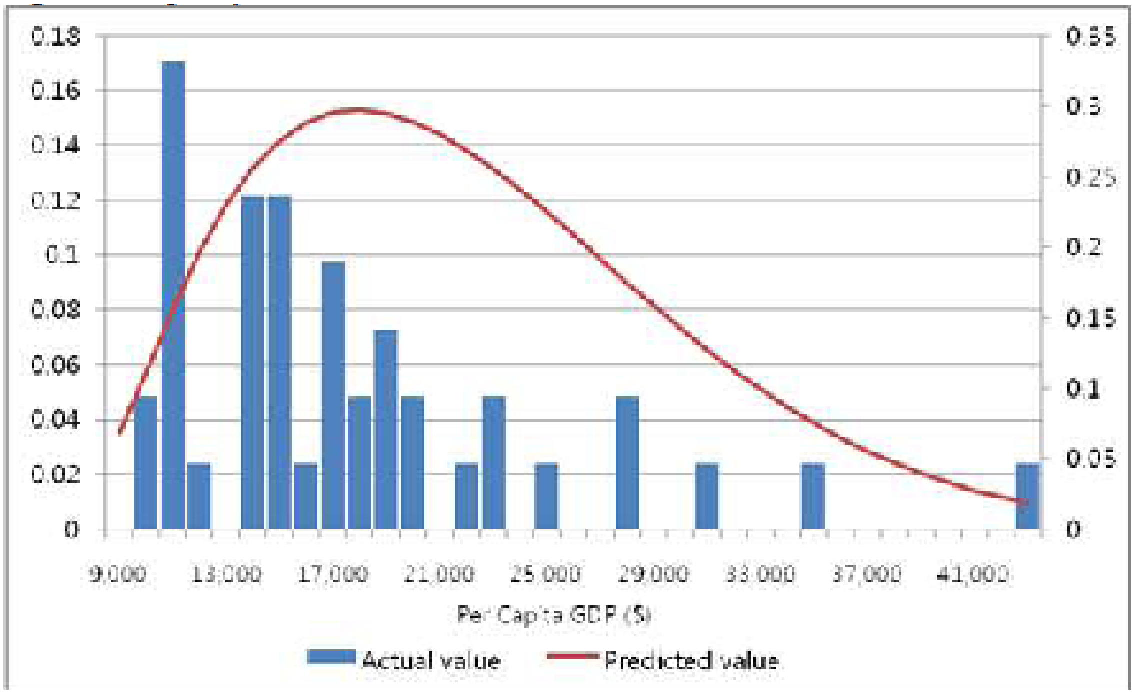
There is a large empirical literature on the determinants of growth using cross-country comparisons, many with contradictory results (e.g. survey by Durlauf, Johnson and Temple

2004). There are some points of agreement; many studies show that high growth is correlated with human capital, investment, openness to trade and institutional variables. There is, however, much less work on changes in growth rates, why some countries manage to raise their pace of development over time or why countries fall into the middle-income trap. Hausmann, Pritchett and Rodrik (2005) showed that growth accelerations are correlated with increases in investment and trade, real exchange rate depreciations and economic reform. Eichengreen et al. (2011, 2013) address one aspect of the middle-income trap issue by examining at what point on the per-capita income scale that such growth slowdowns occur.

Eichengreen et al. (2013) define a slowdown as a fall in growth rates of GDP per capita of at least 2 percentage points between successive 7-year periods. They find that there is a considerable dispersion in the incomes at which slowdowns occur; Figure 3 below reproduces their figure showing the frequency distribution of the per-capita incomes at which this big fall in growth rate occurs. There are two modes in the distribution of the slowdown point, one when per-capita GDP reaches $15,000-16,000 (in 2005 PPP$) and another at around $10,000-11,000[13]. At the median point of the distribution "the growth of per capita income slowed on average from 5.6 to 2.1 per cent per annum." They find that "slowdowns are less likely in countries with high levels of secondary and tertiary education and where high-tech products account for a large share of exports", and "some evidence that financial crises and changes in political regime raise the likelihood of growth slowdowns." We should note that in their dataset the per-capita GDP for China in 2010 is $7129 (in 2005 PPP$).

Figure 3. Frequency distribution of growth slowdown from Eichengreen et al. (2013).

[13] Eichengreen et al. (2013) uses data from the Penn World Tables 7.1 which is derived from the International Comparison Program (ICP). The World Bank database noted in the previous footnote is also derived from the ICP. We note that the revised version, Penn World Tables 8.0, has a significantly higher estimate for China's PPP-adjusted income.



Source: Authors' calculation.

Note: The bars indicate the frequency distribution of actual growth slowdowns by per capita income, and the smooth line is the predictedvalues of growth slowdowns derived from a probit model.

Eichengreen et al. (2011) used an earlier dataset compared to Eichengreen et al. (2013) but focused the discussion on China. They conclude that there are opposing features of the Chinese economy that raises and lowers the probability of a slowdown. "China's openness and high investment rate point away from the likelihood of a slowdown," however, the rising share of manufacturing, the old-age dependency ratio, and the very low share of consumption in GDP "heightens the likelihood of an imminent slowdown". Putting the various factors together lead them to conclude that that probability of a slowdown in China as exceeding 70%.

From the above discussion it is seems fair to conclude that there is a variety of historical experiences in economic development, with only a few general principles about proper development strategy and policy making. Not all countries are stuck in the middle-income status, 13 out of the 101 middle-income countries made it to high-income status in the post-WW2 period, and quite a few more are likely to join them soon. That is, the middle-income trap is really a misnomer, the ascension to high-income levels is a matter of speed, the 13 countries noted did it within 4 decades and many others are likely to do it in 5 or 6 decades. The slowdowns in growth that do occur happen at quite different points in the development paths for different countries. A sizable number of slowdowns occur around $10,000 of per-capita income (2005 PPP$), but there are also many cases where they occur beyond $20,000.

Forecasts of China's growth

Given these ambiguous lessons from past experience it is not surprising to have forecasts of long-term China growth that range from the very optimistic to the pessimistic. Yifu Lin (2011) argues that China in 2008 has an income level that is only 21% of the U.S., the same ratio as that of Korea in 1977 and Taiwan in 1975[14]. There is a "large technological gap between China and the industrialized countries. China can continue to enjoy the advantage of backwardness …" The growth rate of Korea during 1977-97 averaged 7.6% per year, while that of Taiwan during 1975-95 was 8.3%. China thus "has the potential to achieve another 20 years of 8 percent growth." He also noted that even with such a 20-year period of high growth, the Chinese income would still be only about 50% of U.S. income. He reiterated his optimistic outlook in a press briefing in July 2013 (Financial Times 2013)[15].

Such an outcome means that China would have escaped the middle-income trap that afflicted the vast majority of countries as noted above. One should also note that 21% of U.S. income in 1977 is quite a bit lower in absolute terms compared to 21% of U.S. income in 2008, $3770 versus $6720. Pettis (2014) has a more pessimistic outlook, arguing that the past high-investment strategy has led to "increasing investment misallocation." The economic reforms in the Third Plenum in November 2013 aim to rebalance growth towards higher consumption growth and "improving the capital allocation process". Such a reform, Pettis argues, will lead to "healthier but slower GDP growth over the rest of this decade … the minimal amount of rebalancing that has occurred in the past three years has already lopped three percentage points off China's GDP growth." Further reform will improve the functioning of the economy and raise household incomes, but will reduce GDP growth further, with a likely "long landing" outcome where "growth rates will drop by roughly one to two percentage points every year for the rest of this decade." In essence, Pettis is arguing that incomes and consumption can continue to rise at

[14] This uses the same source of data that is in Figure 1 reproduced from World Bank (2013) – the Maddison database.

[15] Justin Lin's remarks are reported by Jamil Anderlini in the Financial Times July 29, 2013 under the headline "Justin Lin criticizes China growth pessimists". He is quoted as predicting China will grow at between 7.5% and 8% for the next 20 years.

5-6% per year even as GDP growth slows to 3-4% because what are being lost are the unproductive investments of the past.

China 2030 point out that the definition of high-income status in the World Bank classification is somewhat arbitrary and expressed in PPP$, and that global growth makes this a moving target. This meant that the growth in income that is needed to reach high-income rank by, say 2030, is a product of the domestic GDP growth (in constant yuan units) and the change in the real yuan-dollar exchange rate. Different assumptions about the rate of real yuan appreciation will change the required growth rate, and they suggest a range of 4 percent to 6.2 percent GDP growth is required for China to just reach high-income status by 2030. We should also note that the band of incomes in the high-income group is large, "the average per capita income of high-income countries is more than three times this threshold level"[16] (World Bank and DRC 2013, p 82).

China 2030 also gives a projection of the economy using the Development Research Center's model of China (World Bank and DRC 2013, p 84). In the main case "assuming steady reforms and no major shock", GDP growth rates are projected to decline from 8.6% per year (2011-15), to 7.0% (2016-2020) and 5.0% (2026-30). The also project the share of consumption in GDP to rise from 56% in 2011-15 to 66% in 2026-30 with a corresponding fall in investment share. The structure of production continues to move from agriculture and manufacturing towards services, with the value added share of services rising from 43% in 2010 to 61% by 2030. Chen and He (2014) provides an updated forecast and a detailed description of the projection methods used in their model which is also the one used in the World Bank and DRC (2013) report. They note that total factor productivity growth of countries that are catching up with the most advanced country start fast but gradually decelerate, and thus project that aggregate TFP growth for China will decelerate from 2.4% per year during 2000-2010 to 1.9% during 2018-2022 period. This contributes to their projected GDP growth slowdown to 6.5% per year during 2018-2022.

The Conference Board (2014) has a more pessimistic long-term outlook for China projecting a growth rate of 5.9% 2014-19, and 3.5% for 2020-2025. An Asian Development Bank study using data from 61 countries up through 2007 (i.e. before the Global Financial

[16] In footnote 11 we noted that the high-income threshold for 2013 is $12,615 (in $ calculated using the Atlas method), and that the U.S. level is $53,670. By this definition, Korea's GNI per capita is $25,920.

Crisis) projected China's growth rate at 6.1% for 2011-2020 and 5.0% for 2021-2030 (Lee and Hong 2010, Table 1). That study used aggregate data (i.e. GDP, aggregate capital and labor data, but not industry level data)[17].

Zhu (2012) provides another review of the literature in an article titled "Understanding China's Growth: Past, Present and Future." He incorporates the results from Brandt and Zhu (2010), which is given in Table 1, into his perspective of the key sources of future growth. He notes that the successful economies – Japan, Korea and Taiwan – started from a level of TFP that is about 50% of the U.S., had a period of rapid TFP growth until they reach about 80% of the U.S. level when there is a sharp deceleration of the catch up in TFP. In 2007, Zhu estimates that China TFP level is only 13% of the U.S. and thus "even if China can replicate this [past] extraordinary growth performance for the next two decades, its productivity level would still be only 40 percent of the frontier U.S. level." He thus thinks that there are still "large opportunities for raising productivity growth through reducing existing distortions and inefficiencies." However, he also notes that there are many obstacles to such improvements and "further institutional change and policy reforms will be needed."

[17] Lee and Hong (2010) ran cross-country growth regressions with right-hand side variables including initial productivity, initial life expectancy, initial capital stock, growth of Research and Development capital, measure of openness and measure of property rights. The results of these regressions are then used in a simple Solow model to project growth for each country.

4. Three growth scenarios with current energy and GHG policies

Given the uncertainty and lack of consensus about future economic growth in China we believe it will be most useful to construct alternative projections of China's economic growth and see what they imply for energy consumption and emissions. We constructed three scenarios for the 2013-2050 period using an economic model that takes into account the sources of growth just discussed – investment and capital input, labor and human capital, reallocation of productive factors between industries and total factor productivity (TFP) growth.

Our central case represents a conservatively optimistic outlook – continued world recovery uninterrupted by major conflicts or disruptions. It recognizes that the highly productive investments in the double-digit growth era are exhausted and returns to investment will be lower going forward. In the optimistic case we incorporate the views that continued high growth of 7-8% may be sustained for a longer time and assume a higher productivity growth rate. This productivity improvement eases the constraints of natural resources on such growth (e.g. less coal or water is needed per unit GDP). In our pessimistic case we assume lower productivity growth resulting in GDP growth slowing towards 4.5% per year by 2020 and 2.7% by 2030. This scenario still envisages an escape from the middle-income trap by the mid-2030s (unless the definition of high income is revised upwards by then).

Our multi-sector growth model of China used to make these projections is described in greater detail in the Appendix. We have noted that the key driver of past growth in China is the accumulation of capital, and so investment in a very important aspect of our model. In the model, investment is financed by savings of the households, retained earnings of enterprises, government investment and investment by foreigners. Annual investment is cumulated into a stock of capital after an adjustment for improvements in the quality of capital, this stock is allocated to the different industries by the market.

Labor input is a function of the working age population and projections of work-force participation rates and educational attainment. The growth of TFP in each industry is set exogenously, i.e. set by assumptions external to the model. For simplicity, we have assumed an equal rate of TFP growth across sectors. Imports and exports are explicitly identified by commodity in the model, and world oil prices play an important role in determining energy consumption (and imports) in this model.

The unusual demographic transition of China has been much noted, how the population is aging before it has reached high income levels that is more typical of countries with a large share of old people. Cai (2010), for example, discusses the end of the “demographic dividend” and the impact of the rapid aging on future growth in China. We take this into account and consider various scenarios of population growth and labor input in our projections. The U.N.’s Population Division provides forecasts by age groups [18] and we adjust them to incorporate the new population policies. For the central and low growth scenarios we have the policy of allowing parents who are single-child to have two children, and for the high growth scenario we have the policy of allowing all families to have two children. We use these population projections to forecast the work force and consider both quantity and quality of labor inputs.

The exogenous parameters and coefficients determining the growth rate in this model are thus the following: savings rate, dividend rate (=1 - rate of retained earnings), rate of capital quality improvement, rate of labor quality improvement, TFP growth, world prices of commodities. The parameter values chosen for our 3 scenarios – Central case, Optimistic case, Pessimistic (Middle-income trap) case – are given in Table 3.

Table 3. Parameters of growth scenarios

	Savings rate	Dividend rate	Popul-ation	Work force	Labor input (quality adjusted)	Productivity index
Base year 2010	41.2%	38.9%	1360	938	100.0	100.0
Central case (2020)	22.3%	57.9%	1440	930	108.5	111.5
Optimistic case (2020)	24.3%	55.9%	1452	930	111.3	112.2
Pessimistic case (2020)	18.3%	61.9%	1440	930	108.5	110.0
Central case (2050)	14.6%	65.5%	1434	758	97.6	144.6
Optimistic case (2050)	16.6%	63.5%	1518	797	117.2	157.7
Pessimistic case (2050)	10.6%	69.5%	1434	758	85.3	137.0

Population and labor projections

[18] The United Nations Population Division data is given on their web page http://esa.un.org/unpd/wpp/unpp/panel_population.htm .

After the November 2013 Plenum there are discussions of relaxing the 1-child policy, with one proposal allowing families to have two children where either parent is a single child. Another proposal would allow all families to have two children. The impact of such changes is estimated by Wang, Hu and Zhang (2013) and we incorporate them into our population and work force projections. In the pessimistic case and central case we assume the policy of allowing 2 children when either parent is a single child. In the high-growth case we assume that all families are allowed to have 2 children.

The projections are plotted in Figure 4 and summarized in Table 3. In the projection under the less relaxed policy total population rises from 1360 million in 2010 to 1433 in 2020 and 1385 in 2050. Under the more generous policy the population is projected to be 1452 in 2020 and 1518 in 2050. The number of working age people, at 930 million, is not changed by 2020 as a result of the 2-child policies but the change is noticeable beyond that; in the high-birth scenario the work force only falls to 797 by 2050 compared to 758 in the low-birth scenario.

Figure 4. Projections of population

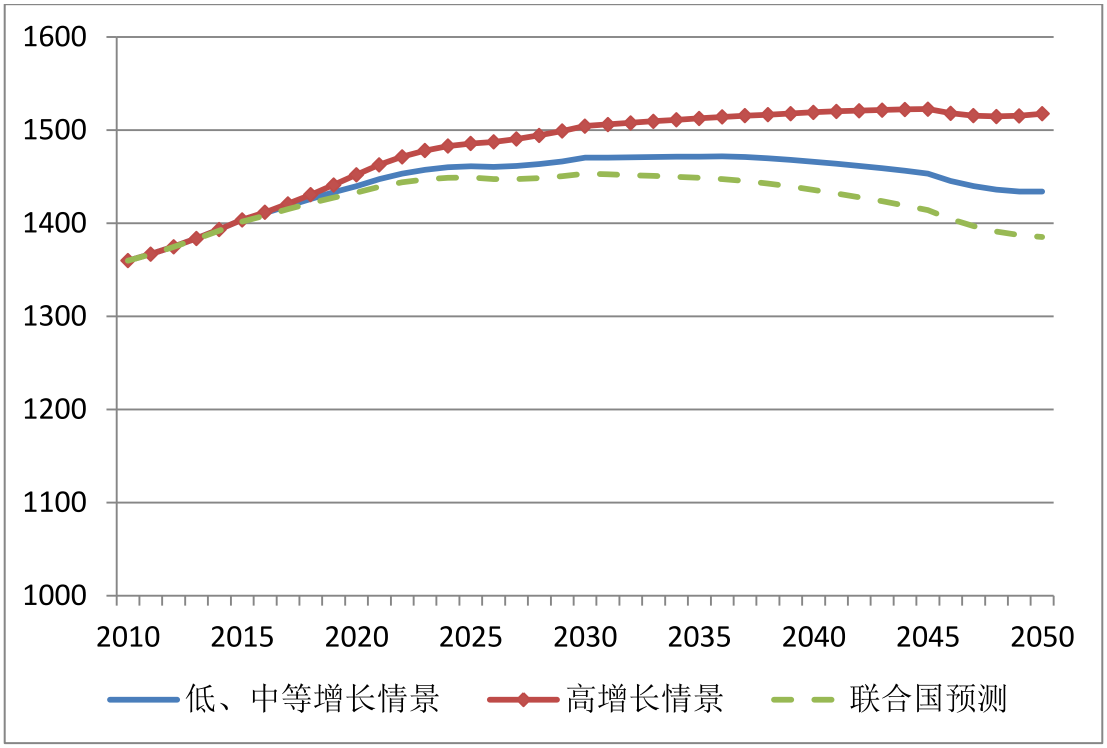
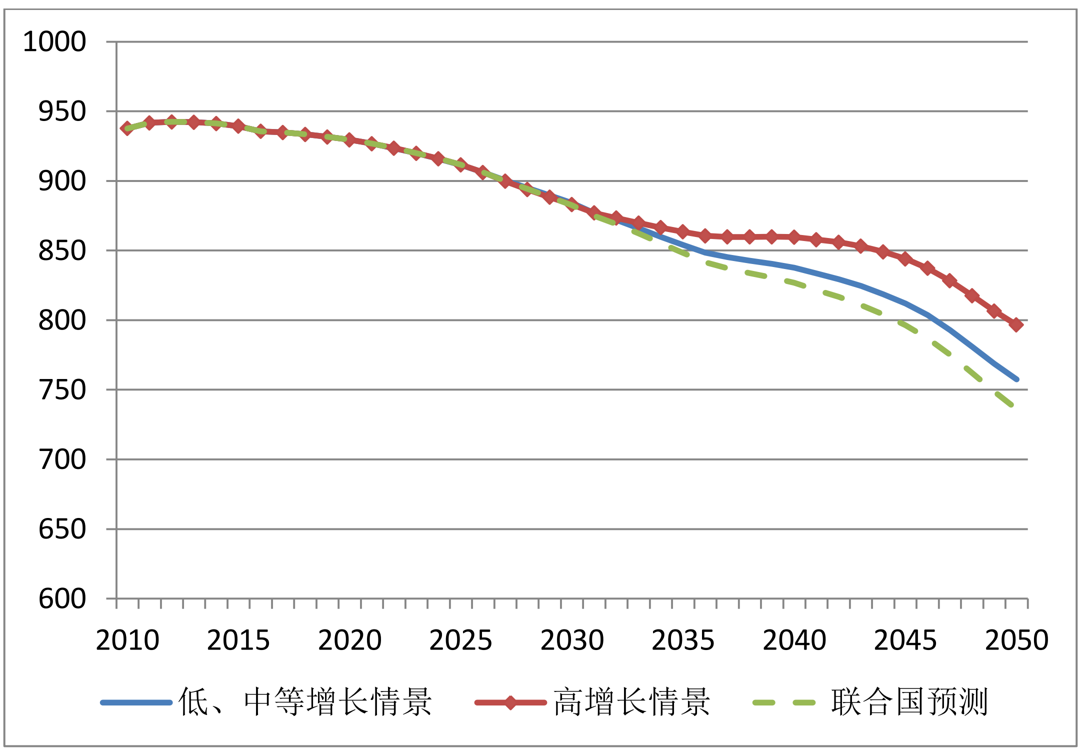


Figure 5. Projection of work force



In our model effective labor input is the number of workers multiplied by an adjustment for the quality of workers. The number of workers is the working-age population multiplied by the labor-force participation rate. We project a rising participation rate as people retire at older ages. The educational attainment of workers has risen dramatically between 2000 and 2013 and we project a continuing improvement in human capital but at a decelerating rate. The result is that effective labor input rises by 0.9% per year in the near term (see Figure 5). The projection of effective labor input is given in the second last column of Table 3, in the central case this rises from 100 in 2010 to 108.5 in 2020 and falls to 102.7 by 2050. In the optimistic case with faster rate of human capital growth, the effective labor input rises to 111.3 in 2020 and to 117.2 by 2050, that is, the rise in labor quality offset the decline in the number of workers.

Productivity projections

The estimates of the sources of growth summarized in Section 2 indicate a total factor productivity growth rate of 2 to 4 percent per year on average at the aggregate level. At the individual industry level the TFP growth rate averages much less than 2 percent, with some manufacturing industries performing much better than the other, mainly services, industries (as explained in Table 2 and footnote 7). Our projections are summarized in the final column of Table 3. In our accounting for the sources of growth in the model we have an explicit term for the growth in capital quality that is not included in most of the studies in Table 1. That is, the TFP estimates in those studies include this capital quality effect. In our projections we separate out capital quality and labor quality from the TFP term. In all scenarios we project a rise in capital quality of 11% between 2010 and 2030, that is, 11% more effective capital input from the same stock. In the central case we project TFP growth that slowly decelerates starting from 1.3% per year in 2010, and by 2020, the level of productivity is 11.5% higher than in 2010, and 44.6% higher by 2050. In the optimistic case the level rises from 100 in 2010 to 112.2 by 2020 and 157.7 by 2050.

Projected scenarios

We put the above projections of the exogenous variables into our model and simulated economic growth out to 2050. The results for the major variables in the central case are given in

Table 4, and for all 3 cases in Tables 5 for two years. The growth rates are summarized in Table 5b, and the projected paths of GDP are plotted in Figure 6 for the three scenarios.

In the central case we project a growth rate of 7.3% for 2010-20, 4.8% for 2020-30 and 3.1% for 2030-50. This is not very different from the World Bank and DRC (2013) projections in *China 2030* (7.0% 2016-20, 5.4% 2020-30). The plans announced in the November 2013 Third Plenum include an aim to raise household incomes and rebalance towards more consumption and less investment; given our assumptions of savings rate and the higher rate of payouts from enterprises to households, our projection has a decline in the investment:GDP ratio from 48% in 2010 to 37% in 2020 and 31% by 2030, with a corresponding rise in the consumption ratio given in Table 4. We project household incomes to rise from 59% of GDP in 2010 to 67% in 2030. (As an example of a recently developed country, South Korea's investment share fell from a peak of 40% in 1991 to 29% in 2007 just before the Financial Crisis. In the U.S. at the peak of the investment boom in 2000 the share was 18%.)

In 2010, China's income was 8228 PPP 2005$ in the World Bank database (footnote 11) and in the base case scenario it would triple to 25,200 PPP2005$ by 2030, bringing it well into the high-income group. In terms of 2010 yuan, the per-capita income rises from 29,500RMB to 91,500 by 2030. If realized, this would indeed be a successful implementation of the reforms.

Table 4. Central case projection.

Variable	2010	2015	2020	2030	2010-20 growth rate
Population (million)	1,360	1,404	1,440	1,470	0.57%
Effective labor supply (billion 2010 yuan)	16,687	17,529	18,100	18,098	0.81%
GDP (billion 2010 yuan)	40,154	59,580	83,424	134,482	7.3%
Consumption/GDP	0.35	0.45	0.51	0.55	
Fossil energy use (million tons sce)	3,249	4,069	4,973	6,399	4.3%
Coal use (million tons)	3,122	3,702	4,208	4,962	3.0%
Oil use (million tons)	441	529	605	683	3.2%
Gas use (million cubic meters)	107,291	188,443	284,365	480,864	9.7%
Electricity use (TWh)	4,194	5,794	7,631	11,327	6.0%
CO_2 emissions (fossil fuel, million tons)	7,388	8,912	10,291	12,366	3.3%
CO2 intensity (kg CO2/yuan)	0.184	0.150	0.123	0.092	-4.0%

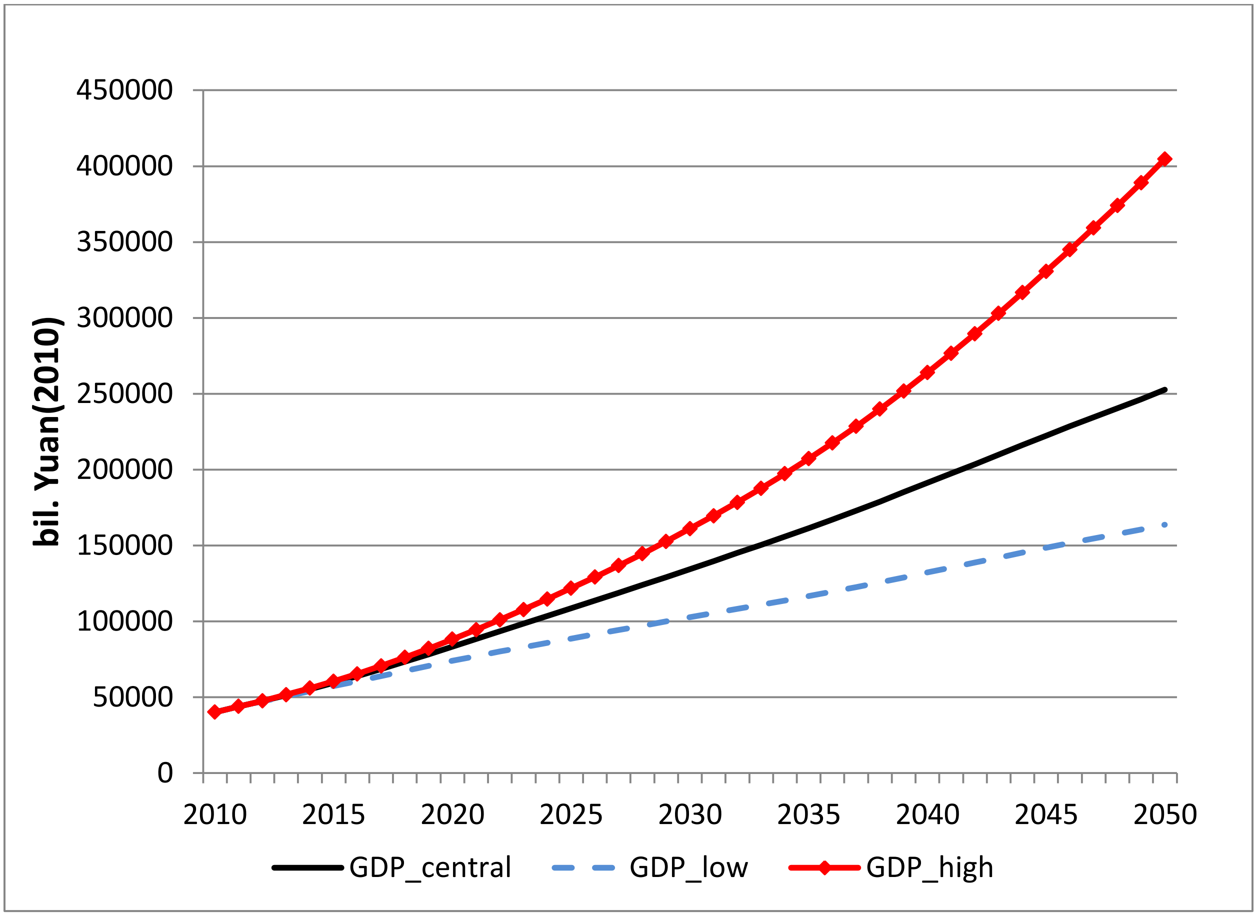
Table 5. Alternative growth scenarios

	Central case		Optimistic case		Pessimistic case	
Variable	2020	2030	2020	2030	2020	2030
Population (million)	1440	1470	1452	1504	1440	1470
Effective labor supply (billion 2010 yuan)	18100	18098	18566	19596	17407	16578
GDP (billion 2010 yuan)	83424	134482	88251	161135	74007	102706
Consumption/GDP	0.508	0.553	0.489	0.533	0.548	0.595
Fossil energy use (million tons sce)	4973	6399	5214	7410	4508	5205
Coal use (million tons)	4208	4962	4444	5834	3757	3945
Oil use (million tons)	605	683	618	733	580	624
Gas use (million cubic meters)	284365	480864	296994	553393	259278	390130
Electricity use (TWh)	7631	11327	8023	13347	6861	8944
CO_2 emissions (fossil fuel, million tons)	10291	12366	10805	14337	9308	10064
CO2 intensity (kg CO2/yuan)	0.123	0.092	0.122	0.089	0.126	0.098

Table 5b. GDP growth rates in alternative scenarios (% per year)

	Central case	Pessimistic case	Optimistic case
2010-2020	7.31%	6.11%	7.87%
2020-2030	4.77%	3.28%	6.02%
2030-2050	3.15%	2.33%	4.60%
2010-2050	4.60%	3.51%	5.78%

Figure 6. GDP Projections in Central, High and Low-growth Scenarios



This rate of growth in the central case is accompanied by a strong growth in energy use and emissions despite the productivity improvements and energy conservation. The use of fossil fuels is projected to grow at 4.3% per year during 2010-20 in the central case. Compared to the GDP rate of 7.3% this implies a substantial decline in energy intensity. Carbon intensity falls from 0.184 kg CO2/yuan of GDP to 0.092 by 2030, falling at a rate of 4.0% per year in the first 10 years. Electricity use however, is projected to rise almost as fast as GDP, just a 1% per year decline in electricity intensity.

In the optimistic growth case with higher productivity growth and higher labor quality we project GDP growth at 7.9% (2010-2020) and 6.0% (2020-30), a full percentage point higher than the central case 2020-30 rate. The per-capita income in 2030 is 107,000 yuan, seventeen percent higher than in the central case. With the higher productivity growth the fall in CO2 intensity is even greater; by 2030 it is 0.089 kg CO2/yuan compared to 0.092 in the central case.

In the pessimistic case the growth rate falls to 3.3% per year during 2020-30 and to 2.3% during 2030-50. In this case per capita incomes are 51,000 yuan in 2020 and 70,000 in 2030, or 19,500 PPP2005$. This still means that China would enter the high-income club as currently defined by the World Bank by the mid-2030s. The investment share of GDP falls faster than in the base case, leading to lower growth of construction services and building materials. Such a shift leads to lower energy growth compared to the base case: (i) lower consumption of all goods due to lower incomes, (ii) a slower growth of automobiles which has an income elastic demand, (iii) a smaller share of output going to energy intensive goods such as cement and steel. These trends mean a lower rate of growth of pollutant emissions and GHG emissions, however, the slower productivity trends mean a small rise in the emission intensity. CO2 intensity by 2020 is 0.126 kg/yuan compared to 0.123 in the central case, and 0.098 versus 0.092 by 2030.

5. Low-carbon policy scenarios

While there have been a lot of discussions of carbon reduction proposals in China there is no consensus plan that command wide support. That is, there is not yet an agreement about the timing and magnitude of the reduction, and the policy instruments to be used to achieve such reduction targets. The specification of the kind of target is itself very significant, whether it is in terms of absolute number of tons of CO2-equivalent, or in terms of carbon-intensity (emissions per unit GDP), or in terms of emissions per capita.

Given the range of growth scenarios discussed in the previous section it would be more appropriate to consider the carbon reduction in terms of intensity. A hard target like “x tons of CO2 by 2030” is much easier to meet in the low growth scenario compared to the optimistic case.

To illustrate the economic impact, we consider a substantial, but not overly ambitious, carbon emission reduction scenario for each of the three growth cases. In the central growth case, our carbon policy leads to a 13% reduction in the carbon intensity by 2030, and a 40% reduction by 2050. This goal still results in an increase in the carbon emissions, peaking around 2030 at 12 billion tons of CO2. In contrast, the “450 Scenario” in the International Energy Agency projections (IEA 2013) has a very ambitious target that would reduce world emissions from 38

Gt in 2035 in the "New Policy" Scenario to 22 Gt. For China, the projected contribution to this global reduction requires a decline in the CO2 intensity (tons of CO2 per unit GDP) from 1.03 in 2010 to 0.18 by 2035 (IEA 2013, Figure 1.17).

Table 6. Carbon emission reduction scenarios versus no-policy Central case

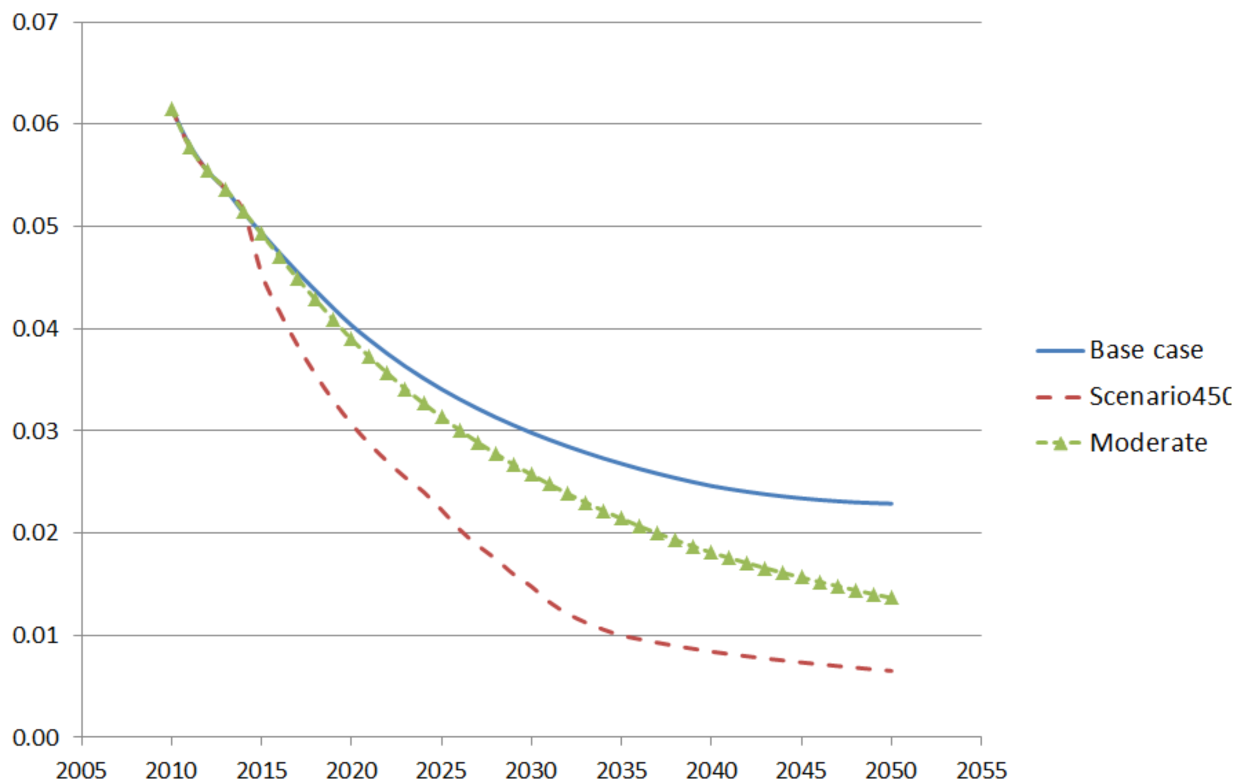
	Central case			Pessimistic case			Optimistic Growth		
	2020	2030	2050	2020	2030	2050	2020	2030	2050
GDP (% change)	-.02%	-.06%	-.48%	-.02%	-.03%	-.28%	-.03%	-.07%	-.72%
CO2 (% change)	-4.6%	-13%	-42%	-4.4%	-11%	-36%	-4.7%	-14%	-48%
CO2 intensity (% change)	-4.6%	-13%	-41%	-4.4%	-11%	-36%	-4.7%	-14%	-47%
Carbon price (yuan/ton CO2)	11.2	22.7	67.5	11.2	22.9	68.6	11.2	22.5	66.3
Carbon tax revenue /GDP	0.25%	0.54%	1.1%	0.24%	0.49%	1.0%	0.25%	0.57%	1.1%

To achieve these steadily rising reductions we introduce a corresponding rising path of carbon taxes into our model where all users of fossil fuels have to pay the tax. The revenues from this new tax are used to cut all existing tax rates proportionately. We simulated the model three more times, once for each growth scenario with the carbon tax.. The aggregate results are reported in Table 6 and the industry results in Table 7, while Figure 7 plots the change in carbon intensity.

Table 7. Industry effects of carbon taxes in 2020.

	Central case		Pessimistic case		Optimistic case	
	Change in Price	Change in Qty.	Change in Price	Change in Qty.	Change in Price	Change in Qty.
Agriculture	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Coal mining	5.5%	-6.1%	5.2%	-5.8%	5.6%	-6.2%
Crude petroleum mining	0.4%	-0.6%	0.4%	-0.5%	0.4%	-0.6%
Natural Gas Mining	1.3%	-1.4%	1.3%	-1.3%	1.3%	-1.4%
Nonenergy mining	0.1%	-0.4%	0.1%	-0.4%	0.1%	-0.4%
Food products, tobacco	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%
Textile goods	0.1%	-0.2%	0.1%	-0.2%	0.1%	-0.2%
Apparel, leather	0.0%	-0.1%	0.0%	-0.1%	0.0%	-0.1%
Sawmills and furniture	0.1%	-0.1%	0.1%	-0.1%	0.1%	-0.1%
Paper products, printing	0.1%	-0.1%	0.1%	-0.1%	0.1%	-0.1%
Petroleum refining, coking	0.5%	-0.6%	0.4%	-0.6%	0.5%	-0.6%
Chemical	0.3%	-0.3%	0.3%	-0.3%	0.3%	-0.3%
Nonmetal mineral products	0.5%	-0.5%	0.4%	-0.4%	0.5%	-0.5%
Metals smelting	0.3%	-0.4%	0.2%	-0.4%	0.3%	-0.4%
Metal products	0.1%	-0.3%	0.1%	-0.3%	0.2%	-0.3%
Machinery and equipment	0.1%	-0.2%	0.1%	-0.2%	0.1%	-0.2%
Transport equipment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Electrical machinery	0.0%	-0.2%	0.0%	-0.2%	0.0%	-0.2%
Electronic & telecom. equip	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%
Instruments	-0.1%	-0.2%	-0.1%	-0.2%	-0.1%	-0.2%
Other manufacturing	0.1%	-0.2%	0.1%	-0.2%	0.1%	-0.2%
Electricity, steam, hot water	1.1%	-1.3%	1.1%	-1.3%	1.1%	-1.4%
Gas production and supply	0.7%	-0.8%	0.7%	-0.7%	0.7%	-0.8%
Construction	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%
Transportation	0.0%	-0.2%	0.0%	-0.1%	0.0%	-0.2%
Communications	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Trade	-0.1%	0.1%	-0.1%	0.1%	-0.1%	0.1%
Accomodation & Food	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Finance and insurance	-0.1%	0.0%	-0.1%	0.0%	-0.1%	0.0%
Real estate	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%
Business services	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Other Services	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Public administration	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 7. Reduction in CO2 Intensity Relative to No-Policy Central Case



In the Central case CO2 emissions are required to fall by 4.6% in 2020 compared to the no policy base case, to achieve this reduction the carbon tax rate is a modest 11 yuan/ton of CO2 (in 2010 yuan), resulting in the price of coal being 5.5% higher than in the base case. The revenue from this carbon tax comes to 0.25% of GDP, or 1.2% of total government tax revenues. By 2030 the carbon tax rises to 0.54% of GDP (2.5% of total government revenue) to achieve the 13% reduction in CO2 emissions. The CO2 emissions will peak at about 11.8 billion tons around 2030, and then decline gradually to 11.2 billion in 2050. This increase in the price of coal raises the price of electricity significantly, and the prices of energy intensive goods (Chemical, Metals, Nonmetal mineral products) rise relative to the cleaner commodities such as Apparel and Services.

The rise in the price of energy intensive goods as a result of the carbon tax changes the pattern of production as shown in Table 7; coal and electricity output falls significantly while there is an expansion of some of the cleaner service industries (e.g. Trade and Real Estate). These price changes lead to a reduction in investment and thus a lower stock of capital over time.

This reduces aggregate GDP slightly, by 2020 GDP is 0.02% lower than in the base case, and 0.06% lower by 2030.

In the pessimistic growth case, the carbon reductions are much smaller in absolute terms but the fall in carbon intensity is similar. In 2020 the CO2 price is 11.2 yuan per ton, the same as in the central growth case. , By 2030 the carbon tax revenue is only 0.49% of GDP compared to 0.54% in the Central case. The lower fossil fuel prices in the Pessimistic carbon policy case lead to a smaller change in the output of coal and other energy-intensive goods and a smaller change in GDP compared to the Central case.

In the high growth Optimistic case where there is higher productivity growth (i.e. a faster improvement in energy per unit output) the similar carbon prices generate a bigger decline in carbon intensity. By 2030, the carbon tax of 22.5yuan/ton (compared to 22.7 in the Central policy case), generates a reduction in the intensity of 13.7 percent (compared to 12.8 percent). By 2050 the reduction in intensity is 47 percent compared to a 41 percent reduction in the Central policy case. However, these changes in a more productive growth case means a bigger fall in GDP, -0.72 percent in 2050, compared to -0.48 percent in the Central case.

While there is a GDP cost, and a reduction in consumption, to achieving a carbon emission reduction, we should note that the costs are modest in aggregate terms. There are sharp reductions in the output of specific industries but the fall in overall GDP is less than 1%. One factor contributing to this modest fall in material welfare is the use of the carbon tax revenues to reduce existing taxes. Cao, Ho and Jorgenson (2013) shows how alternative uses of these revenues may result in higher costs.

6. Conclusion

Long term projections of the economy are subject to many sources of uncertainty. They are almost certainly forgotten 20 years after they are made. We have discussed when it is important to get them right, and when it is less so. If we are aiming for a target set in absolute tons of CO2-equivalent then it makes a big difference if the growth rate is 7 percent or 4 percent per year. If we are aiming at an intensity target then it is probably of less importance to be very certain of the growth forecast. One exception to this is when the sources of high economic growth are also the sources of new ideas and innovation in dealing with environmental problems.

That is, if growth is driven by clever new ideas then those clever people may also be coming up with clean energy ideas. In that case one has the best of both worlds of rising incomes and improving environmental protection.

Climate risks are, unfortunately, related to absolute concentration, not to emissions per unit GDP. This means we have to devote more effort to reducing risks by reducing emissions when output is rising faster. However, the very nature of this issue makes it easier to solve, the richer society gets, the easier it should be to devote more resources to environmental protection. At 7 percent annual growth, allocating 1% of GDP to energy efficiency and development of renewables is much easier than at 3 percent growth.

Our simulations indicate a modest cost to reducing CO2 emissions if we use a carbon price and recycle the revenues by reducing existing taxes. Many other studies, for China and other countries, have also come to the same conclusion – efficient market mechanisms would encourage a decentralized search for low-carbon technologies and energy efficiency and result in a small cost to welfare (e.g., Paltsev et al. 2007 estimate of welfare cost between 0.5% and 2%, and Nordhaus 2010 estimates 1 to 1.5% of national income to meet the 2°C goal). While a broader consideration of equity, uncertainty and political constraints require a more sophisticated analysis of policy instruments (taxes, subsidies, performance standards, etc.), analysis such as Goulder and Parry (2008) provide a framework for efficient policy design. China's rapid improvement in incomes justifies a greater effort at reducing local and global pollution.

Appendix. A multi-sector growth model of China.

To analyze the impact of energy and environmental policies on economic growth we use a dynamic multi-sector model of the Chinese economy. The model is described in detail in Cao, Ho and Jorgenson (2013, Appendix A), and is summarized here. In this model, economic growth is driven by labor force growth, capital accumulation, growth in total factor productivity and reallocation of production factors across sectors. It is a "dynamic recursive" model, meaning that investment (capital accumulation) is driven by exogenously specified saving rates, in contrast to "intertemporal general equilibrium" models where saving rates are endogenously determined within the model. It is a general equilibrium model where prices adjust to equate demand and supply in each commodity and factor market.

The production side of the economy is divided into the 33 industries listed in Table 4. Total supply comes from the output of these domestic industries and imports. Production in each industry is characterized by constant returns to scale, so that output in a given period expands in proportion to inputs. Energy intensity for each industry (energy use per unit output) is a function of input prices and an intensity parameter that is projected to change over time. The change in the externally specified energy intensity parameter is often called the "autonomous energy efficiency improvement (AEEI)". For the U.S. there is a long time series of data on energy use and prices on a consistent classification, and Jorgenson et al. (2013) were able to estimate such an energy intensity function and rate of AEEI for their model of the U.S using 50 years of data.

However, for China, such a long consistent time series is not available. Instead, we project the energy intensity parameter for each industry using input-output tables from China and the U.S. More specifically, the parameter is projected such that the share of energy in total costs for each industry gradually resembles the share in the U.S. in 1997 (i.e. the shares fall from the higher levels in the 2007 Chinese input-output table to the lower shares in the U.S. over a 40-year period). The same procedure is used to project the contributions of coal, oil, gas and electricity to total energy use, except that we recognize that the share of coal will likely continue to be higher in China than in the U.S in 1997. The estimates of total factor productivity growth (TFP) at the industry level and at the aggregate level are quite mixed as noted in Table 2. Cao et al. (2009) estimate TFP growth between -1.5% (Petroleum Refining) to 5.6% (Electrical Machinery) per year for the manufacturing industries over the period 1982-2000. Wu (2007) estimates for manufacturing TFP growth during 1993-2005 are generally much higher, e.g. 12.8% (Electrical Machinery), 10.8% (Instruments). TFP growth for each industry in China is projected to match the current high growth rate of about 3 percent per year before tapering off.

On the demand side, total demand consists of intermediate demand as well as final demand from households, government, investment and exports. The parameters of the household consumption function are projected to change to capture the rising share allocated to automobile, gasoline and electricity consumption. The rapidly rising share of exports and its changing composition are also projected exogenously. An interesting trend is that exports of energy- and pollution-intensive goods (petroleum products, chemicals, primary metals and non-metallic mineral products), derived from the Chinese benchmark input-output tables, actually fell from 13.5 percent of total exports in 1992 to 10.7 percent in 2002。 The pollution intensity of Chinese exports is discussed in greater detail in Dean and Lovely (2008).

The environmental module incorporates the first five steps of the pollution impact pathway described in the third section, including the emission coefficients for coal, oil and gas for each industry, the intake fractions, dose-response coefficients, and valuations of health effects.

The model was calibrated to the 2010 input-output table, with aggregate data on the quantity of coal, crude oil, natural gas and electricity coming from the *China Statistical Yearbook* and *China Energy Statistical Yearbook*, and industry level TSP and SO_2 emissions coming from the *China Environment Yearbook.* Estimates of NO_x emissions are from the transportation sector come from Wang et al. (2007). Estimates of CO2 emissions are from China Energy Data book v8.0[19].

[19] http://china.lbl.gov/research-areas/china-energy-databook

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