12 Will Chinese Industry Ever Be 'Green'?

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Introduction

In January 2013, as air pollution reached record levels in much of eastern China, Chinese multimillionaire Chen Guangbiao sold cans of air on the street in smog-ridden Beijing to send a simple message: 'I want to tell mayors, county chiefs and heads of big companies: don't just chase GDP growth, don't chase the biggest profits at the expense of our children and grandchildren and at the cost of sacrificing our ecological environment'.¹ As a temporary response to the 'hazardous' air quality in Beijing, with particulate matter readings reaching over 40 times those considered safe by the World Health Organisation, the municipal government temporarily shut down more than 100 heavily polluting factories and ordered 30 per cent of government vehicles off the roads.² It is clear (pardon the pun), however, that these emergency measures are not long-term solutions, with the transition towards a new model of economic growth now widely considered to be an imperative, not an option.

This imperative is reflected in the World Bank's report *China 2030*, which states that: 'It is clear that however global carbon budgets may be allocated via national actions and international negotiations over the next twenty years, there will never be enough carbon emission space for China to copy the past industrialisation model of developed countries' (2012: 235). One of the six key characteristics of the report's proposal for a 'New Development Strategy for 2030' is the concept of green development, 'a pattern of development that decouples growth from heavy dependence on resource use, emissions and environmental damage, and promotes growth through the creation of new green products, technologies, investments, and changes in consumption and conservation behaviour' (2012: 233).

Given the dominance of industry in generating China's aggregate carbon dioxide emissions (at 86 per cent of the country's 8.2 billion tons in 2010), a sustainable pattern of industrial growth will be a critical component of the transition towards a green, low-carbon economy. Traditionally, a rising share of total-factor productivity (TFP) in output growth has been taken as a signal of

1 'Chinese Millionaire Fights Pollution with Thin Air', 30 January 2013, Reuters, available at <http://www.reuters.com/article/2013/01/30/us-china-pollution-cans-idUSBRE90TOLM20130130>

2 'Beijing Shuts Factories, Removes Cars, but Pollution Stays High', Reuters, available at <http://www.reuters.com/article/2013/01/29/us-china-pollution-idUSBRE90S0AJ20130129>

the transformation towards a 'sustainable' development model based on quality rather than quantity; that is, on intensive rather than extensive growth (Solow 1957; Krugman 1994; Young 1995). There have been many studies assessing the contribution of TFP to China's economic growth since 1978, with ongoing debates about whether and when its development model has made this transformation.³ Most of these studies use Solow residuals or regressions based on Cobb-Douglas (CD) or translog production functions to estimate productivity, while some use parametric stochastic frontier production functions and others utilise data envelopment analysis (DEA). In much of the existing literature, however, measures of productivity have been calculated using data that only includes the traditional inputs of capital and labour, neglecting both the energy inputs required for economic growth and their environmental impacts.⁴ Even if these measures were to reveal a rising and, at some point, dominant share of TFP in output growth, this neglect surely raises questions about the true sustainability of the evolving growth model.

There is a range of alternative measures for evaluating a country's development performance, which take these issues into account; for example, by incorporating energy as an intermediate input in the production process (as in the KLEM model of Jorgenson et al. 1987), or by treating emissions as an unpaid and unobservable input in the production function (Mohtadi 1996). In our view, however, none of these measures accurately accounts for the negative externalities associated with emissions generated in the production process. In contrast, the directional distance function (DDF), (Chung et al. 1997), incorporates an emissions variable as an undesirable output directly into the production function, which enables an explicit evaluation of the negative impact of emissions growth on a country's production frontier using DEA analysis. This results in a measure of TFP growth known variously as actual, total, environment-sensitive, or green TFP (henceforth GTFP), which can be separated into efficiency and technical change components.

There have been wide applications of this approach outside China,⁵ but only a few on China to date. For example, one analysis (Hu et al. 2008) uses DDF to re-rank the technical change and efficiency of Chinese provinces once energy and emissions are taken into account, and shows different rankings compared to the more traditional measures (e.g. Zheng and Hu 2005). A 2010 study (Wang et al.) estimates Chinese regional-level TFP and finds that changes in GTFP and TFP deviate from each other, with GTFP suffering mainly from the over-emission

3 See Wu (1995, 2008); Woo (1998); Young (2003); Bosworth and Collins (2008); and, Jefferson et al. (2000, 2008) for a sample of a large list. Chen et al. 2011 provide a recent survey of this literature.

4 One exception is Chen (2009), who includes both energy and carbon dioxide emissions as input factors in China's growth accounting to estimate the productivity growth of 38 Chinese industrial sectors for the period 1980–2006.

5 For examples, see Hailu and Veeman 2000; Jeon and Sickles 2004; and 2006.

of sulphur dioxide and chemical oxygen demand. Another study (Tu 2008) estimates only China's regional environmental efficiency, but not productivity, while this chapter does both below. Furthermore, none of these studies conduct their analysis at this chapter's high level of industrial disaggregation.

This chapter uses DEA and the DDF to estimate the changing patterns of GTFP growth of 38 industrial sectors during the period 1980–2010 to assess whether Chinese industry is on the path towards a sustainable form of low-carbon growth or not. Unfortunately, as will become clear below, it seems to have lost its way.

Method and Data

DEA is a nonparametric linear programming method for estimating a production frontier with multiple inputs and outputs. A comparison with the best-practice frontier enables the identification of each inefficient decision-making unit (DMU) and its relative efficiency value, as revealed by its distance from the frontier.⁶ There are numerous different specifications of emissions⁷ within the DEA framework, which rely on different distance functions to calculate productivity indexes that can then be separated into efficiency and technical change components. Below, three alternative specifications are considered: one in which emissions are ignored altogether (Model 1); one in which they are treated as a desirable output (or good), using the Shephard distance function (Model 2); and one that treats emissions as an undesirable output (or bad) using the directional distance function (Model 3).

We use a panel dataset of 38, two-digit industrial sectors between 1980 and 2010, classified according to the 2002 version of the National Standard of Industrial Classification (GB/T4754) and developed by Chen (2011). Each sector is classified as a DMU, which produces a desirable output (measured as industrial value added (IVA) at 1990 prices) and an undesirable output (carbon dioxide emissions) using three inputs, capital, labour and energy. The capital stock cannot be obtained directly and is estimated using the perpetual inventory approach, depreciated at constant 1990 prices of investment in fixed assets. The labour input is annual average employed workers and the energy input is total energy consumption, measured in tons of coal equivalent (TCE). Total energy is sourced from coal, petroleum, natural gas and electricity, each of which has a different emission factor. The quantity of emissions (measured in tons) for each sector is calculated by multiplying the quantity of each energy source by its emission factor and summing across all sources.

⁶ See the pioneering work of Farrell 1957 and Charnes et al. 1978.

⁷ We focus on carbon dioxide emissions in this chapter, although the approach can readily be applied to other emissions as well. For ease of reference, we use 'emissions' to refer to carbon dioxide emissions for the remainder of the chapter.

Figure 12.1 illustrates the DEA method for models 2 and 3 (but not Model 1, since it does not measure emissions). Technology is represented by the output set $P(\mathbf{x})$ to which the output vector of point $(\mathbf{y}, \mathbf{b})$ belongs, where $\mathbf{y}$ is the good (IVA) and $\mathbf{b}$ is the bad (emissions). Linear programming is used to calculate the value of the distance function for each DMU (i.e., sector) at a fixed point in time. In the case of Model 3, the directional distance function (DDF) increases IVA and simultaneously reduces emissions for a given level of inputs, by scaling from point A in the direction along AB, represented by the direction vector $\mathbf{g}=(\mathbf{y}, -\mathbf{b})$. In contrast, the more commonly used Shephard distance function (SDF) used in Model 2 radially scales the original vector from point A proportionally to point C to describe the simultaneous increase in both IVA and emissions. The key difference between the two models relates to their assumptions about the disposability of bads. In particular, the assumption of strong or free disposability of bads in SDF implies that disposing of them costs nothing, whereas the weak disposability assumption of bads in DDF implies that the disposal of bads is costly (i.e., requiring the diversion of inputs to achieve this end, or non-zero mitigation costs). The latter seems a far better representation of reality, which is why Model 3 is our preferred model.

Figure 12.1 The directional and Shephard distance functions

Source: Authors' schema.

In models 1 and 2, TFP is estimated by computing the Malmquist productivity index whereas, in Model 3, GTFP is estimated by calculating the Malmquist–Luenberger productivity index, which explicitly credits an increase in good outputs and a proportional reduction of bad outputs. Both productivity indexes (PI) can be decomposed into an efficiency index (EI) and a technical change index (TI). If there have been no changes in either inputs or outputs between two points in time, then $PI=1$, while an improvement (deterioration) in productivity is signaled by $PI>1$ ($PI<1$). EI measures the change in output efficiency between two periods, reflecting the movement of each DMU either towards ($EI>1$) or away from ($EI<1$) the frontier. TI measures the shift in the production frontier between two time periods. If technical change enables higher production of goods and lower production of bads (i.e., a shift of the production

frontier towards the north-west), then $TI > 1$; whereas $TI < 1$ implies a shift of the frontier in the direction of fewer goods and more bads. All of these indices can be converted to average annual growth rates to provide a more familiar indication of the performance of Chinese industry over time in terms of productivity, efficiency and technical change. Positive (negative) growth rates in all cases correspond to indexes greater (less) than one.

Figure 12.2 China's aggregate industrial energy and emissions, 1980–2010

Source: Industrial dataset described in the text and authors' calculations.

Before presenting these estimates, Figure 12.2 illustrates the aggregate trends in levels of energy consumption and emissions, along with their intensities (with aggregate IVA in the denominator), as revealed by our dataset. This combination of trends reflects the rapid growth of industrial output, which has resulted in a dramatic rise in emissions in the last decade, despite the steady reduction in intensity over time.

Table 12.1 presents the IVA, emissions and emission intensities of each industrial sector in 2010 and the growth rates of IVA and emissions for the period 1980–2010. Not surprisingly, there is substantial heterogeneity across sectors. The largest emitter of carbon dioxide in 2010 is the electric- and heat-power sector, generating over three billion tons. Another five heavy-industrial sectors emitted over 400 million tons each—petroleum, coking and nuclear fuel processing (listed in the table as petrol processing); ferrous metal smelting and pressing; non-metal manufactures; coal mining; and chemicals—compared with 'just' 900,000 tons for the lowest emitting sector, cultural, sports and educational articles. Of course, high emissions do not necessarily imply high emission intensity, as they may, instead, be due to high levels of output. The overlap is significant, however, with the top five emission-intensive sectors being petroleum, coking, and nuclear fuel processing; electric and heat power; coal mining; petroleum and natural gas extraction; and gas production and supply.

Table 12.1 Levels and growth of key variables by sector

Sector	Levels (2010)			Growth (1980–2010, %)	
	IVA	Emissions	Emission intensity	IVA	Emissions
Total industry	11,333	7,188.6	634	12.6	6.4
Coal mining	152	438.5	2,881	8.7	5.5
Petrol. extraction	26	71.0	2,766	2.0	4.0
Ferrous metal mining	59	3.0	51	14.7	3.4
Non-F. metal mining	50	1.8	37	10.1	-0.2
Non-metal mining	63	14.5	231	7.3	5.5
Logging	7	1.3	181	1.1	-2.5
Food processing	331	33.8	102	13.2	3.8
Food manu.	162	20.7	128	13.9	2.7
Beverages	221	15.7	71	13.3	3.1
Tobacco	260	1.8	7	12.1	1.6
Textiles	450	46.4	103	9.1	1.7
Apparel	212	4.2	20	14.3	6.5
Leather	106	1.7	16	13.3	0.2
Wood processing	177	8.9	50	16.6	3.2
Furniture	79	0.6	8	13.6	-0.1
Paper	172	82.2	479	12.2	5.9
Printing	89	0.9	10	11.2	-1.6
Cultural articles	59	0.4	7	13.5	1.0
Fuel processing	44	1,688.7	38,181	2.6	6.7
Chemicals	628	416.4	663	11.3	4.1
Medicine	370	14.0	38	16.5	3.6
Fibers	85	14.3	168	13.9	1.8
Rubber	108	9.1	84	10.9	2.0
Plastic	260	8.7	33	15.4	6.2
Nonmetal manu.	550	492.6	895	11.1	6.2
Ferrous smelt/press	437	576.4	1,319	10.6	5.3
Non-F. smelt/press	248	58.3	235	12.8	6.8
Metal products	327	7.1	22	12.2	1.4
General machines	641	9.6	15	12.6	-1.7
Special machines	404	12.9	32	12.2	0.6
Transport equip.	1,018	19.7	19	17.9	1.2
Electrical equip.	865	12.4	14	15.9	3.4
Electronic equip.	2,014	4.4	2	24.3	1.5
Measuring inst.	166	0.6	3	14.0	-1.0
Electric & heat power	301	3,059.7	10,152	9.9	8.6
Gas	18	27.2	1,517	11.4	3.3
Water	7	0.5	63	6.7	4.1
Others	164	8.7	53	12.5	-1.0

Note: IVA - billions of yuan, emissions - millions of tons, intensity - tons/million yuan.

Source: Industrial dataset described in text and authors' calculations.

One piece of good news here is that none of the top five sectors in terms of emissions levels or intensities are in the top ten fastest growing, or the top ten largest sectors in terms of IVA. Another is that in only two of the 38 sectors

(petroleum processing and petroleum and natural gas extraction) did the growth of emissions exceed that of IVA over the period, suggesting that the downward trend in emission intensity shown in Figure 12.1 has been industry wide, not sector specific. Emissions growth, however, was only negative in a handful of sectors, providing an early indication that GTFP is likely to be higher, not lower, than the more traditional TFP estimates. More generally, the data summarised in Figure 12.2 and Table 12.1 highlight the magnitude of the challenges facing China as it attempts to decouple the rapid growth of industrial production from that of energy use and emissions.

China's Industrial GTFP Growth, 1980–2010

The average annual growth rates of Chinese industry's productivity, efficiency and technical change between 1980 and 2010, weighted by the IVA share for each sector and averaged geometrically over the sample period for each of the three models specified above, are reported in Table 12.2.

Table 12.2 Growth of productivity, efficiency and technical change in Chinese Industry, 1980–2010

	Model 1 (Ignore emissions)	Model 2 (Emissions as good)	Model 3 (Emissions as bad)
Productivity	5.5 ***	4.4 **	1.8
Efficiency	0.9 **	0.8 *	-0.1
Technical change	4.7	3.7 *	2.0

Note: Null hypothesis of the t test is that the estimated productivity, technical progress and efficiency of models 1 and 2 are identical to those estimated by model 3. ***, **, * indicate that the level of significance is 1%, 5% and 10%, respectively.

Source: Industrial dataset described in text and authors' calculations.

According to Model 1, the growth of TFP, efficiency, and technical change were 5.5 per cent, 4.7 per cent and 0.9 per cent, respectively. Productivity is lower when emissions are included as a good in Model 2, and this reduction is almost entirely due to lower technical change, indicating that the inclusion of emissions impacts mainly on the location of the production frontier, rather than on the movement of individual sectors towards or away from the frontier over time.

Based on our preferred model, Model 3, the average annual growth rates of GTFP, technical change and efficiency between 1980 and 2010 were 1.8 per cent, two per cent and -0.1 per cent, respectively. Like TFP, this indicates that improvements in China's GTFP have resulted from technical change rather than efficiency improvements, which is consistent with findings based on traditional measures (e.g., Wu 1995 and Zheng et al. 2003). Indeed, at this aggregate industry level, there appears to have been a backwards step in terms of latter (indicated by $EI < 1$, or the negative growth rate seen in Table 12.2). The GTFP

growth estimated by Model 3 is less than the estimates of models 1 and 2, and all the measures surveyed by Chen et al. (2011), apart from the 1.8 per cent estimate by Wing Thyee Woo (1998). The estimates of efficiency and technical change contained in Model 3 are also smaller than those of models 1 and 2, although the difference between the technical change estimates of models 1 and 3 is not statistically significant (see note under Table 12.2).

Figure 12.3 illustrates the change in aggregate industrial GTFP growth and its components over time. Through the 1980s, GTFP growth remained low, and was even negative at times, before experiencing a long and steady increase through the 1990s to peak at 4.2 per cent in 2002, followed by a continuous decline since then to reach just half a per cent in 2010. As the figure illustrates, the rise and fall of China's GTFP has been driven by the rise and fall in technical change, while efficiency has fluctuated at low levels throughout the period of analysis.

Figure 12.3 Growth rates of GTFP, efficiency and technical change

Source: Industrial dataset described in the text and authors' calculations.

Table 12.3 takes a closer look at the aggregate-level productivity results for the entire period and for three distinct sub-periods. Following Chen et al. (2011), and because of the varying patterns of energy consumption and emissions, the reform period is classified into three sub-periods: 'slow and steady' (1980–1995), stagnant (1996–2002), and rapid growth (2003–2010). For each period we report the average annual rate of growth of IVA, emissions, capital, labour, energy and productivity (TFP or GTFP) from each of the three models, averaged over the 38 sectors. Over the entire period, and for each sub-period, capital and energy are the dominant contributors to growth in terms of inputs. During the period

1996–2002, energy consumption and emissions grew by their lowest annual rate (hence 'stagnant') while labour growth was negative. These figures contrast starkly with the rapid growth of energy and emissions in the most recent period, at over ten per cent each.

Table 12.3 Average annual growth rates of outputs, inputs and productivity (%)

Period	IVA	Emissions	Capital	Labour	Energy	Productivity		
						Model 1	Model 2	Model 3
1980–1995	8.5	5.9	9.8	3.7	5.7	1.4 (17%)	1.2 (14%)	0.9 (10%)
1996–2002	12.6	2.8	5.8	–2.9	3.0	10.1 (80%)	6.4 (51%)	3.9 (31%)
2003–2010	21.1	10.2	11.0	4.6	10.1	10.6 (50%)	8.5 (40%)	2.1 (10%)
1980–2010	12.6	6.4	9.3	2.6	6.3	5.5 (44%)	4.4 (35%)	1.8 (14%)

Note: For each period, the numbers in brackets report the contribution share of each productivity estimate to IVA growth, equal to 100 minus the share of all inputs.

Source: Industrial dataset described in the text and authors' calculations.

The first key message from Table 12.3 is that, by accounting for the negative impact of energy-related emissions in Model 3, productivity estimates in all sub-periods are below the traditional estimates. Similar to the findings in Table 12.2, for each period the estimates of productivity growth for models 1 and 2 are greater than the corresponding estimates for Model 3, with the only exception being Model 2 in the first sub-period.

The figures in brackets in Table 12.3 indicate the percentage contribution of TFP (for models 1 and 2) and GTFP (for Model 3) to the growth of IVA, revealing the second key message of Table 12.3. According to the traditional estimate of Model 1, TFP accounted for 80 per cent of output growth between 1996 and 2002, and one half of it between 2003 and 2005, supporting claims that growth has been predominantly intensive, rather than extensive since the mid 1990s. When emissions are included in Model 3, however, GTFP accounted for only 32 per cent of IVA growth in the second period, falling to 10 per cent in the third. Furthermore, the productivity contribution estimated by all three models decreased between the second and third periods.

The first two columns of Table 12.4 present the average annual growth rates of TFP, and GTFP and its components for each sector between 1980 and 2010. The combination of growth rates of IVA and emissions for each sector shown in the final two columns of Table 12.1 are useful for understanding the differences between the TFP and GTFP results reported in Table 12.4. Each sector's productivity growth depends on both the change in that sector's input–output combination between two points in time, and the shape of the production frontier near that combination at the initial point in time. As long as frontier production of the good increases when output of the bad increases

(as we would typically expect), the relative values of TFP and GTFP depend not only on the growth in emissions between the two points in time, but also on this growth *relative* to that of output (Jeon and Sickles 2004). The standard and most intuitive case is where GTFP growth rates are less than TFP growth rates because emissions growth is positive: simply put, emissions growth is penalised in the 'green' estimate. This was the case in coal mining, ferrous metal mining, and another 27 sectors, and in aggregate in Table 12.3. The other intuitive case, in which GTFP growth is higher than TFP growth because emissions growth is negative, occurred in just two sectors, logging and 'others'.

In another five sectors (non-ferrous metal mining, furniture, printing, general machines and measuring instruments), even though emissions growth is negative, GTFP is still lower than TFP because the fall in emissions growth is small relative to the increase in IVA growth (for example, -0.1 per cent versus 13.6 per cent respectively for furniture). Finally, there is one perverse result, the petroleum extraction sector, in which emissions growth exceeds IVA growth and yet GTFP is greater than TFP (0.1 per cent compared with -1.3 per cent). As one study explains (Jeon and Sickles 2004), this might happen because of limited data in the neighbourhood of this sector (which is likely, given its high ranking in terms of emission intensity) and because the production frontier in that neighbourhood does not necessarily expand in the direction of more IVA, even with an increase in emissions.

Table 12.4 also presents the growth rates of efficiency and technical change for each sector between 1980 and 2010. As for the aggregate results illustrated in Figure 12.3, technical change is the dominant source of GTFP growth in virtually all sectors, peaking at an average annual rate of 6.3 per cent in the electronics sector, and recording positive values in all but one sector (petroleum, coking and nuclear fuel processing). In contrast, efficiency recorded negative growth in 28 sectors and was greater than one per cent in just two sectors (electronics and electric and heat power).

In amongst the pessimistic news is the slightly consoling fact that GTFP growth was positive in all but three sectors over the first three decades of reform. But, does this signal the transformation of industry towards a sustainable, low-carbon, intensive model of growth? The answer is an emphatic no. The final three columns of Table 12.4 show the contribution of GTFP to output growth in each sector for the three time periods. Between the first two periods, this contribution increased in 28 of the 38 sectors, and in the second period GTFP accounted for more than half of IVA growth in five sectors, and for more than 20 per cent in another 12 sectors. Between the second two periods, however, the contribution of GTFP fell in 34 of the 38 sectors and, in the third period, it only exceeded a half in one sector (tobacco) and was greater than 20 per cent in just another three. This, combined with the other evidence presented in this section, signals a setback in the low-carbon transformation of Chinese industry in recent years.

Table 12.4 TFP, GTFP, Efficiency and technical change across sectors and time

Sector	Av. annual growth (1980–2010, %)				Share of GTFP in IVA growth (%)		
	TFP	GTFP	Effic.	Tech	1980–95	1996–2002	2003–10
Coal mining	2.7	0.0	–0.1	0.1	0.2	0.6	–0.0
Petrol. extraction	–1.3	0.1	–0.7	0.8	15.5	–1.4	0.2
Ferrous metal mining	4.1	0.7	–0.2	0.9	7.4	7.5	1.7
Non–F. metal mining	3.7	0.8	–0.4	1.1	5.8	24.8	4.2
Non–metal mining	1.5	–0.1	–1.0	0.9	–4.2	–4.4	0.6
Logging	–0.4	0.1	–0.6	0.7	–4.6	19.8	–9.0
Food processing	1.7	0.3	–0.2	0.5	2.1	3.6	1.5
Food manu.	3.2	0.3	–0.1	0.4	2.2	4.2	0.9
Beverages	1.4	0.5	–0.2	0.8	3.7	12.7	1.9
Tobacco	5.6	2.6	–0.0	2.6	–12.4	44.3	68.7
Textiles	0.3	0.3	–0.4	0.7	5.0	7.1	1.1
Apparel	5.9	1.7	–1.5	3.3	13.4	24.4	5.3
Leather	6.6	2.1	–0.2	2.3	16.8	31.0	8.2
Wood processing	5.5	1.0	–0.1	1.1	7.1	15.9	1.9
Furniture	7.1	2.6	–0.1	2.7	19.0	30.7	15.2
Paper	2.2	0.1	–0.1	0.2	1.0	1.3	0.2
Printing	9.1	2.7	–0.3	3.0	32.0	27.0	15.3
Cultural articles	8.4	3.7	–0.6	4.3	23.6	53.3	20.9
Fuel processing	–0.6	–2.4	–1.5	–0.9	315.5	56.1	–42.3
Chemicals	3.3	0.1	–0.1	0.1	0.9	0.6	0.2
Medicine	4.2	2.5	0.0	2.5	4.8	34.8	14.6
Fibers	8.9	0.4	–0.0	0.4	1.6	4.4	3.9
Rubber	1.0	0.4	–0.3	0.7	4.7	6.9	1.4
Plastic	7.1	1.4	–0.7	2.1	7.4	29.8	1.2
Nonmetal manu.	2.6	0.0	–0.1	0.1	0.1	1.1	0.2
Ferrous smelt/press	3.1	0.0	–0.1	0.1	0.7	0.4	–0.4
Non–F. smelt/press	3.4	0.1	–0.3	0.4	0.1	1.5	0.4
Metal products	6.6	1.4	–0.5	1.9	13.2	24.9	5.2
General machines	9.1	1.7	0.0	1.7	16.7	25.3	7.6
Special machines	8.1	1.0	–0.2	1.2	14.2	13.4	3.2
Transport equip.	9.7	1.5	0.1	1.4	10.6	8.6	6.3
Electrical equip.	9.4	3.3	–0.2	3.5	20.8	36.2	12.2
Electronic equip.	19.3	8.4	1.9	6.3	30.7	54.8	21.9
Measuring inst.	11.2	5.4	0.2	5.2	25.3	64.4	39.0
Electric & heat power	7.5	1.5	1.3	0.2	29.5	43.6	–10.0
Gas	5.5	–0.0	–0.0	0.0	0.5	0.0	0.1
Water	1.1	–0.1	–2.2	2.1	–1.9	50.4	3.3
Others	2.4	2.5	0.1	2.4	6.9	109.3	15.2

Source: Industrial dataset described in text and authors' calculations.

Policy Implications

It is worth noting that the average annual growth of aggregate industrial output (measured by IVA) was 12.6 per cent between 1996 and 2002, a period in which the vast majority of sectors recorded their lowest output growth but also enjoyed their highest rate of GTFP growth. In contrast, aggregate output grew at a whopping 21.2 per cent in 2003–2010, with virtually all sectors recording their highest output growth in this period but also reduced rates of GTFP growth. Do these results imply that low-carbon growth can only be achieved by slower economic growth or, conversely, that rapid economic growth can only be achieved by incurring high, and increasingly intolerable, environmental costs?

According to the World Bank (2012: 233), the answer is no: The world's development process is at a crossroad. Given the unsustainability of current economic growth both in China and the world, a new approach is needed. The concept of green development is such an approach. Green development can become a potentially transformative process for the economy, society, the environment, and the role of government. It is an opportunity: an open door.

The report outlines the mix of market incentives, regulations, public investments, industrial policy and institutional developments that China plans to use in order to seize the opportunity to 'go green', including ways to 'encourage new investments in a range of low-pollution, energy- and resource-efficient industries that would lead to greener development, spur investments in related upstream and downstream industries and services and build international competitive advantage in a global sunrise industry' (World Bank 2012: xvi).

Within this new growth strategy, emerging green industries, including clean energy markets (solar-, wind-, and hydro-power), biotechnology, high-end manufactures and clean-energy vehicles, will be supported by new incentives for innovation and research that are intended to make China a world leader in key green technologies and products. Almost 40 per cent of China's RMB4,000 billion (US\$584 billion) fiscal stimulus package, which was launched in November 2008, was allocated to green themes, while Chinese investment in renewable energy became the world's largest in 2009, reaching more than US\$20 billion (Robins et al. 2009). These are just two examples of steps that could result in the significant expansion not only of China's own production frontier, but of the global frontier as well, enabling technical progress to become a strong driver of productivity growth and putting China's industrial GTFP back on track in the years ahead. The Chinese leadership's ongoing commitment to green, low-carbon development, as evidenced by the adoption of these and numerous other energy-saving and emission-abating policies and regulations in recent years, will be absolutely critical for turning this potential into reality.

The 'green transformation' of traditional sectors is another crucial component of the green growth strategy, with the focus on energy-efficient investments that will yield high economic returns. For example, the report cites the fact that, although Chinese cement makers have reduced their energy intensity by 30 per cent between 1998 and 2009, they are still 30 per cent less efficient than global best practice, while China's iron and steel industry could potentially save more than 100 million tons of coal per year. In combination, these two industries could save an average of US\$9.9 billion per year between 2008 and 2030 by using the best energy-saving technologies currently available, with even greater savings given future possible energy price trajectories and technological advances. In other words, there is potential for efficiency gains that will move individual sectors towards both China's and the global production frontier, raising their GTFP in the process.

Conclusions

Any effort to account for the environmental costs of economic growth comes with practical challenges, including how to weight carbon dioxide (and other) emissions in the absence of prices and/or reliable estimates of the costs of the damage they inflict. The directional distance function (DDF) uses the Malmquist–Luenberger productivity index to overcome this problem by penalising emissions growth in proportion to rewarding output growth, with the underlying presumption being that 'consumers have preferences for reducing bad outputs regardless of the actual damage resulting from those outputs' (Färe et al. 2001: 382). This may appear to some as an extreme way of assessing a country's economic—or industrial—growth performance. But then, desperate times call for desperate measures, and the image of Chen Guangbiao selling canned air to masked customers in Beijing is a powerful symbol of the desperate extent of China's environmental problems.

This chapter uses DEA analysis and the DDF to estimate 'green' TFP and its components for 38 Chinese industrial sectors between 1980 and 2010, focusing on the damage caused by high and rising carbon dioxide emissions. The results reveal that China's industrial GTFP growth estimated in this way is significantly lower than productivity estimates that do not account for the negative impact of carbon dioxide emissions generated in the production process. Throughout the sample period, both in aggregate and for the majority of sectors, GTFP growth has been predominantly shaped by technical change, which increased steadily from the mid 1990s to the early 2000s, but which has declined continuously since then, in contrast with fluctuating but generally low rates of efficiency growth. GTFP growth was positive in the majority of sectors and in aggregate, both over the entire period and in each sub-period. The most worrying sign,

however, was that between 2003 and 2010 GTFP growth was not only low (and well below the 50 per cent level that is often taken to signal the transition to 'sustainable' growth), but also lower than it was in the preceding decade. This trend is not in the direction that the Chinese leadership, or anyone else, is hoping for. GTFP and its components offer a useful tool for assessing whether China is progressing towards its goal of becoming a green, low-carbon economy. With the most recent evidence indicating that Chinese industry seems to have lost its way on what remains a long road ahead, some may wonder whether it will ever be green? It is far from guaranteed, but there is definitely hope.

Acknowledgments

Shiyi Chen acknowledges the support from National Natural Science Foundation (71173048), National Social Science Foundation (12AZD047), Ministry of Education (11JJD790007), Shanghai Leading Talent Project and Fudan Zhuo-Shi Talent Plan.

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