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'Green' productivity growth in China's industrial economy

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ABSTRACT

This paper uses a Directional Distance Function (DDF) and the Malmquist–Luenberger Productivity Index to estimate the changing patterns of 'green' total factor productivity (GTFP) growth of 38 Chinese industrial sectors during the period 1980–2010. Unlike the measures of traditional total factor productivity (TFP) growth, the DDF incorporates carbon dioxide emissions as an undesirable output directly into the production technology, which credit sectors for simultaneously reducing their emissions and increasing their output. Our estimates of aggregate and sector-level GTFP growth reveal that Chinese industry is not yet on the path towards sustainable, low-carbon growth. A dynamic panel data analysis of the determinants of GTFP across sectors is used to identify factors that might rectify this situation, including state owned enterprise (SOE) reform, the growth of small private enterprises, continued openness to foreign investment and higher spending on R&D, particularly in emission-intensive sectors.

1. Introduction

China's economic model has delivered phenomenal rates of growth over the last three decades, resulting in the country's rise to the front and centre of the global economic stage. However, that model has also favoured exports and investment over domestic consumption, capital over labour, state-owned enterprises (SOEs) over the private sector, and the economy over the environment, culminating in an economy described by former Premier Wen Jiabao as 'unstable, unbalanced, uncoordinated and ultimately unsustainable'.[2]

The imperative for a new model of growth is reflected in the World Bank's (2012) *China 2030* report, which proposes a 'new development strategy for China through to 2030'. This strategy highlights the need for structural reforms that will strengthen the foundations of a market-based economy (including restructuring SOEs, encouraging the private sector and reforming capital, land, labour and energy markets) and accelerate innovation and technological progress. The strategy also stresses the benefits 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 behavior' (p. 233). The report makes it abundantly clear that solutions to China's environmental problems are inextricably linked to reforms that will rebalance the economy and set it on course for sustainable growth in the decades ahead, with many of its recommendations being adopted at the Third Plenum of the Central Committee of the Chinese Communist Party in November 2013.

An appropriate measure of 'sustainable growth' is essential for assessing whether the Chinese government stands any chance of succeeding in their latest reform endeavour. Traditionally, a rising share of total factor productivity (TFP) in output growth has been taken as a signal of 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). Using a range of different methods – including Solow residuals or regressions based on Cobb–Douglas (CD) or translog production functions, parametric stochastic frontier production functions and data envelopment analysis (DEA) – ongoing debates revolve around whether

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[2] Wen Jiabao first made this declaration in March 2007 and has repeated it often since then, most recently in his final report as Premier in March 2013.

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and when China made this transformation.[3] However, in most of this research, TFP is calculated by using just capital and labour as inputs into the production function, neglecting both the energy inputs required for economic growth and their environmental impacts. This neglect diminishes the relevance of this literature for assessing the true sustainability of China's evolving growth model, particularly given the clear preference of the Chinese government for a 'green, low-carbon model' in the future.

The directional distance function (DDF) introduced by Chung et al. (1997) addresses this issue by incorporating an emissions variable (or variables) as an undesirable output directly into the production technology, 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). This method simultaneously credits reductions in bads (emissions) and increases in goods in the estimation of a production frontier under the framework of data envelope analysis (DEA). The Malmquist–Luenberger productivity index calculated by using the estimated DDF scores is a measure of TFP known variously as actual, environmentally-sensitive, or green TFP (henceforth GTFP).

There have been wide applications of this approach outside China, including firm level, industrial level and cross-country analyses,[4] but only a few on China to date. Hu et al. (2008) focus on carbon dioxide emissions and use DDF to calculate the GTFP of Chinese provinces, which leads to different provincial rankings compared with the more traditional TFP measures of, say, Zheng and Hu (2005). Wang et al. (2010) estimate Chinese regional-level TFP and find that changes in GTFP and TFP deviate from each other, with GTFP suffering mainly from the emissions of sulphur dioxide and chemical oxygen demand. Likewise, Zhang et al. (2011) also conduct a provincial-level analysis and, by using a more complete set of pollutants, demonstrate that GTFP growth is lower when these pollutants are incorporated as undesirable outputs in a DDF framework. The regional focus of these papers, however, is quite different from the sector-level analysis conducted here.

This paper uses directional distance function (DDF) and Malmquist–Luenberger productivity index to estimate the GTFP growth of 38 Chinese industrial sectors between 1980 and 2010. Our results reveal that China's industrial GTFP growth estimated in this way is significantly lower than traditional TFP growth estimates that credit a producer for expanding the production of good outputs but do not consider the output of bads, such as emissions. The most worrying sign is that GTFP growth in the last decade was not only low, but also lower than it was in the preceding decade. An examination of the determinants of GTFP growth, and how these determinants differ from those of TFP growth, confirms that many of the reforms currently under consideration by the Chinese government could place China on a truly sustainable path towards low-carbon growth in the future.

2. Measuring 'sustainable low-carbon' growth

DEA is a nonparametric linear programming method for estimating a production frontier with multiple inputs and outputs, originating in the pioneering work of Farrell (1957) and Charnes et al. (1978). A comparison with the best-practice frontier enables the identification of each inefficient decision-making unit (DMU) and its relative efficiency value, revealed by its distance from the frontier. There are numerous different specifications of emissions within the DEA framework, which rely on different distance functions to calculate productivity indexes. This paper considers two alternative specifications: one in which carbon dioxide emissions (henceforth 'emissions') are ignored altogether (Model 1); and one that treats those emissions as an undesirable output (or bad) using the directional distance function (DDF) proposed by Chung et al. (1997) (Model 2).[5]

Assume that there are n DMUs at time t, k types of input, l types of desirable output (or goods), and m types of undesirable output (or bads) for each DMU. For the ith DMU ($i = 1, 2, \ldots, n$), the column vectors $\mathbf{x}_i$, $\mathbf{y}_i$ and $\mathbf{b}_i$ represent the inputs, goods and bads, respectively. X_{kxn}, Y_{lxn}, $C_t = \sum_{i=1}^{3} C_{i,t} = \sum_{i=1}^{3} E_{i,t} \times NCV_i \times CEF_i \times COF_i \times (44/12)$ and $\mathbf{B}_{m \times n}$ are the input and output matrices containing all of the DMUs. In this study, each DMU is one of the 38 Chinese industrial sectors with $k = 3$, corresponding to capital, labour and energy and $l = 1$, corresponding to output.[6] In the case of model 1, $m = 0$, while in the case of model 2, $m = 1$, correspond to the emissions associated with the energy input.

Fig. 1 illustrates the principle of the directional distance function (DDF) for our preferred model 2. 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 desirable output (goods) and $\mathbf{b}$ is the undesirable output (bads). Linear programming is used to calculate the value of the distance function for each DMU at a fixed point in time (as detailed in Appendix 1). The DDF increases desirable output and simultaneously reduces undesirable output for a given level of inputs, by scaling from point A in the direction along AB, represented by the direction vector $\mathbf{g} = (\mathbf{y}, -\mathbf{b})$.[7] The key difference between the two models therefore relates to their treatment of emissions: model 1 excludes emissions and only credits a producer with an increase in good outputs, while model 2 credits producers with a reduction in emissions and a simultaneous increase in good outputs. The weak disposability assumption of emissions in the DDF of model 2 implies that the disposal of emissions is costly (i.e., requiring the diversion of inputs to achieve this end, or non-zero mitigation costs).

In model 1, TFP growth is estimated by computing the change in the Malmquist productivity index (MPI) between time t and $t + 1$, whereas in model 2, GTFP growth is estimated by computing the change in the Malmquist–Luenberger productivity index (MPLI) between time t and $t + 1$. Both MPI and MPLI can be decomposed into an efficiency change index and a technical progress index (see Appendix 1 for further details). If there have been no changes in either inputs or outputs between two points in time, then both productivity indexes for a given DMU will equal one, while an improvement (deterioration) in productivity is signalled by an index greater (less) than one. If a DMU has moved closer to (further away) from the production frontier between two points in time, then the efficiency change index will be greater (less) than one. The technical progress index measures the shift in the production frontier itself. If technical change enables higher (lower) output and lower (higher) emissions then the index is greater (less) than one.

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 growth, efficiency change and technical progress. Positive (negative) growth rates in all cases correspond to indexes greater (less) than one. This method also enables us to calculate the contribution of productivity growth to output growth, with the remainder stemming from growth of inputs. Consistent with

[3] See Chen et al. (2011) for a comprehensive survey.

[4] At the firm level see for example, Boyd et al. (2002) and Picazo-Tadeo et al. (2005); at the industry level see Färe et al. (2001), Shestalova's (2003), Camioto et al. (2014) and Olanrewaju et al. (2012); and at the country level see Jeon and Sickles (2004), Kumar (2006) and a comprehensive survey by Zhou et al. (2008). In a more distantly-related paper, Fujii et al. (2010) use firm-level data to assess the energy efficiency of China's iron and steel sector in the 1990s, during which time they find a continuous improvement in environmentally-sensitive productivities (i.e. GTFPs).

[5] 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 paper.

[6] The DEA method assumes that DMUs are homogeneous in terms of the nature of operations they perform, and the conditions under which they operate. At the industry level, this implies, for example, that each sector is operating under a similar market structure, with similar access to technology and factor input supplies, and so on. We acknowledge that this assumption is likely to be violated in our analysis here, as indeed it would be in regional level or cross-country analyses, and that this is a weakness in the empirical analysis.

[7] Note that this is not the only specification of a DDF that can be used to treat emissions within the DEA framework: another possible specification is one that increases the good while holding the bad constant (i.e., with the DDF heading vertically from point ($\mathbf{y}$,$\mathbf{b}$) to the production frontier), as in Färe et al. (2007), Boyd et al. (2002) and Jeon and Sickles (2004).