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Energy efficiency and productivity change of China's iron and steel industry: Accounting for undesirable outputs

Feng He[b], Qingzhi Zhang[a,b,*], Jiasu Lei[a], Weihui Fu[b], Xiaoning Xu[b]

[a] School of Economics and Management, Tsinghua University, Beijing 100083, China
[b] Dongling School of Economics and Management, University of Science & Technology Beijing, Beijing 100083, China

HIGHLIGHTS

- ► The results indicated inefficiency in many of the plants.
- ► The average energy efficiency was only 61.1% over 2001–2008.
- ► Productivity growth was mainly due to technical shift and scale efficiency growth.
- ► The true TFP growth was underestimated if undesirable outputs were ignored.
- ► Environmental regulation has the potentially positive impact on technical change.

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ABSTRACT

This paper used data from 50 enterprises in China's iron and steel industry to evaluate their energy efficiency and productivity change. The study first used a conventional data envelopment analysis model and the Malmquist Productivity Index (MPI) to measure the energy efficiency and productivity change over the period 2001–2008. The results indicated inefficiency in many of the plants: The average energy efficiency was only 61.1%. The annual growth rate of productivity was 7.96% over this period and technical change was the main contributor to this growth. The research then took undesirable outputs into consideration by using the Malmquist–Luenberger Productivity Index (MLPI) to explore the productivity change from 2006 to 2008. Omitting undesirable outputs would result in biased efficiency change and technical change. This paper also claimed that environmental regulation has a potentially positive impact on technical change.

1. Introduction

China's iron and steel industry has made an impressive progress in the past decades and become the world's largest steel producer since 1996. China's crude steel production grew at an average annual growth rate of 13.9% from 101.24 million tons in 1996 to 626.65 million tons in 2010. China's share of world steel production leaped from 13.5% to 44.3% during the period 1996–2010 as shown in Fig. 1 (China Iron and Steel Statistics Annual Report, 1996–2011). Though large in its absolute size, this industry has many problems such as low technology efficiency, heavy environmental pollution as well as huge energy consumption. It accounts for about 15.2% of the national total energy consumption, 14% of the national total wastewater and waste gas, and 6% of the total solid waste materials generated (Guo and Fu, 2010). As seen from Fig. 2, the total energy consumption of this industry increased from 182.14 million tons in 1996 to 473.39 million tons in 2010 (China Iron and Steel Statistics Annual Report, 1996–2011). Although its comprehensive energy consumption per ton of steel has declined from 1123 to 619 kg of coal equivalent during this period, there still is a wide gap compared to the developed countries (Lin et al., 2011). China's iron and steel industry is an energy-intensive sector as well as a major pollution source among all the manufacturing industries in China.

Some studies have been done on efficiency and productivity of China's iron and steel industry. Early research mainly focused on the impact of economic reform of 1970s on the efficiency of this sector (Jefferson, 1990; Kalirajan and Cao, 1993). With the rapid economic growth since 1990s, more researchers were interested in China's iron and steel industry (Wu, 1996; Zhang and Zhang, 2001; Ma et al., 2002; Movshuk, 2004). Those researches had a diverse focus, including the effects of firm ownership, firm size,

* Corresponding author at: School of Economics and Management, Tsinghua University, Beijing 100083, China. Tel.: +8610 6233 3657.
E-mail address: Kathy101cn@gmail.com (Q. Zhang).

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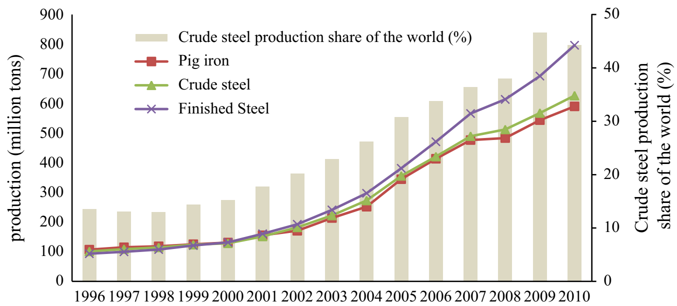

Fig. 1. Total production of China's iron and steel industry and share of the world.

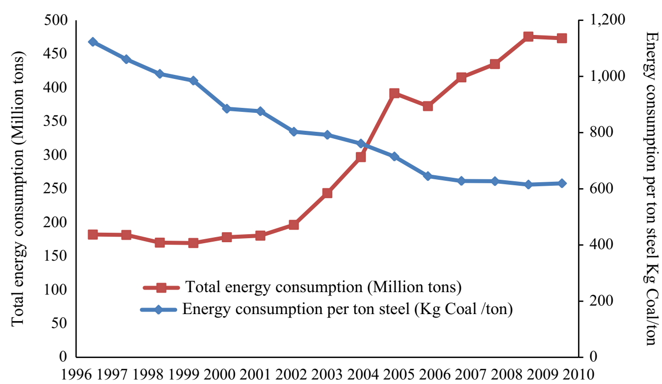

Fig. 2. Total energy consumption and energy consumption per ton steel.

product structure, and regional differences on efficiency and productivity. At present, China's iron and steel industry attracts the researchers' attention not only for its productivity growth, but also for its energy consumption and environmental problems. Wei et al. (2007) investigated China's iron and steel industry energy efficiency during 1994–2003 through provincial panel data. The results indicated that the energy efficiency in China's iron and steel sector increased by 60% between 1994 and 2003, which was mainly attributable to technical progress rather than technical efficiency improvement. Zhang and Wang (2008) found that the increase of technique updating and transformation investments associated with energy conservation enhanced the productive efficiency of Chinese iron and steel enterprises. Using Japan's current energy efficiency level as a baseline, Lin et al. (2011) evaluated the potential future energy efficiency gap of China's steel industry. They found the energy-saving potential of China's steel industry was more than 200 million tons coal equivalent in 2008.

However, those above studies paid little attention to undesirable outputs when estimating energy efficiency and productivity of China's iron and steel industry. Besides, there was no research on the effect of environmental regulation on technical change or productivity change of China's iron and steel industry. In the process of steel production, energy and other materials serve as the inputs that produce both desirable and undesirable outputs such as waste gas, wastewater, and solid waste which may lead to environmental damage. The traditional measures on energy efficiency and productivity growth ignored undesirable outputs and this may lead to a biased evaluation (Chung et al., 1997). Hailu and Veeman (2001) studied productivity improvement in the Canadian pulp and paper industry and found conventional measures that ignore undesirable outputs underestimate true productivity growth. Kumar (2006) examined conventional and environmentally sensitive total factor productivity (TFP) in developed and developing countries over the period 1971–1992. The results showed that those developing countries had lower productivity growth when undesirable outputs were weakly disposable, but the reverse was the situation in developed countries. Watanabe and Tanaka (2007) examined the efficiency levels of Chinese industry at the provincial level while incorporating both desirable and undesirable outputs and found that omitting undesirable outputs led to an overestimate of industrial efficiency levels in some provinces in China. Mandal (2010)estimated energy efficiency of Indian cement industry and the results revealed that energy efficiency estimates were biased if only desirable output was considered. Zhang et al. (2011)came to the similar conclusions that productivity growth appeared to differ while undesirable outputs were considered or not. Thus, it would be important to consider both undesirable outputs as well as desirable outputs when measuring industrial efficiency and productivity (Zhou and Ang, 2008).

In this context, it makes sense to take pollutants into account when exploring energy efficiency and productivity growth of China's iron and steel industry. We will mainly answer the following three questions. First, how has the energy efficiency and productivity changed in China's iron and steel industry during the recent years without undesirable emissions? Second, does undesirable output, if considered in the production process along with desirable output, affect estimates of productivity? Third, does environmental regulation which makes disposal of undesirable output a costly activity have an impact on productivity change?

The remainder of the paper is organized as follows. Section 2 presents the methodology and Section 3 describes the data and variables. The empirical results are presented in Section 4. The final section presents the conclusions.

2. Methodology

We examined the energy efficiency by using the method of analysis proposed by Farrell (1957). The Farrell efficiency measurement consists of two components: technical efficiency and allocative efficiency. The former refers to the ability to make optimal use of existing resources; that is, the ability of a production unit to produce as much output as the inputs allow, or the ability to minimize the inputs given certain levels of output. The latter requires achieving input (output) optimal proportions for given prices and production technology.

2.1. *Traditional efficiency analysis model*

Since Farrell's introduction of the concept of efficiency, a variety of methods to estimate efficiency have appeared. Among those methods, data envelopment analysis (DEA), a well-established non-parametric approach, has been widely used to evaluate the relative efficiency of a set of comparable entities called decision-making units (DMUs) with multiple inputs and outputs (Cooper et al., 2000). The purpose of DEA is to construct a non-parametric envelopment frontier covering all sample data such as all observed points lie on or below the frontier (Coelli, 1995). The points lying on the production frontier are regarded as the efficient DMUs. Inefficient DMUs are those points operating below the production frontier, and the efficiency is then a measure of the distance between the observed level of production and the production frontier. In this article, we first use traditional DEA model which ignores bad outputs and focuses only on the production of good outputs to evaluate energy efficiency (EE) and its decompositions, pure technical efficiency (PTE) and scale efficiency (SE). These decompositions allow an insight into the source of inefficiencies. PTE is obtained by estimating the efficient frontier under the assumption of variable returns to scale (VRS).