Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Firm-level environmentally sensitive productivity and innovation in China

Hidemichi Fujii [a], Jing Cao [b], Shunsuke Managi [c,d,*]

[a] Graduate School of Fisheries and Environmental Sciences, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan
[b] Tsinghua University, 128 Shunde Building, Beijing, China
[c] Urban Institute, Department of Urban and Environmental Engineering, School of Engineering, Kyushu University, 744 Motooka, Nishiku, Fukuoka 819-0395, Japan
[d] QUT Business School, Queensland University of Technology, Level 8, Z Block, Gardens Point, 2 George St, Brisbane, QLD 4000, Australia

HIGHLIGHTS

- This study proposed an identification matrix for firm-level CO_2 reduction activities.
- A directional distance function and the Luenberger productivity indicator are applied.
- The data cover 562 Chinese manufacturing firms from 2005 to 2009.
- Technical innovators are primarily observed in the textile, paper, steel, and computer industries.

ARTICLE INFO

Article history:
Received 19 February 2016
Received in revised form 27 April 2016
Accepted 8 June 2016
Available online xxxx

Keywords:
Technical innovator
Total factor productivity
Technology adoption
CO_2 emissions
Chinese manufacturing firm

ABSTRACT

This study analyzes productive efficiency in relation to CO_2 emissions using a unique dataset of 562 Chinese manufacturing firms for the period from 2005 to 2009. We develop a directional distance function approach to identify technical innovators in the area of CO_2 emissions. The results indicate that a large number of technical innovators are observed in the textile, paper, steel, and computer industries. Furthermore, there are clearly different trends in productivity change and corporate performance across industries and provinces. This result implies that policy makers need to consider industrial and regional characteristics to develop effective policies that conserve energy and reduce CO_2 emissions.

1. Introduction

In light of the increasing concern about China's severe air pollution and energy security, the Chinese government has initiated a series of binding policy targets to address these challenges [1]. One of the government's most prominent successes was the eleventh Five Year Plan, which not only achieved an annual GDP growth of 11.2% but also improved energy efficiency by 19.1% from 2005 to 2010; the original targets had been 7.5% GDP growth and a 20% energy efficiency improvement. There was a rebound in energy use and carbon emissions during the later period of the eleventh Five Year Plan that was attributable to the stimulus package developed in response to the global economic crisis, but the overall effects, particularly the rapid energy intensity decline that occurred between 2006 and 2009, were significant. Given the new challenges related to China's intended nationally determined contribution (INDC) carbon-reduction target, understanding how China dramatically reversed—i.e., effectively curbed—its stable or potentially increasing trend in energy usage during the eleventh Five Year Plan is crucial for designing and implementing successful energy and climate policies. Our paper focuses on environmentally sensitive productivity and technical innovators and provides an ex post firm-level analysis that should help in designing more effective climate policies to achieve the INDC target for the post-2020 era.

The success of China's 11th Five Year Plan in energy savings and pollution reduction is primarily attributable to the energy-saving activities of the non-electricity manufacturing sector in China, whose share of energy consumption was approximately 28% in 2009. Fig. 1 shows the trends in energy consumption related to value added (VA) and carbon dioxide (CO_2) emissions from 1995

* Corresponding author at: Urban Institute, Department of Urban and Environmental Engineering, School of Engineering, Kyushu University, 744 Motooka, Nishiku, Fukuoka 819-0395, Japan.
E-mail address: managi.s@gmail.com (S. Managi).

http://dx.doi.org/10.1016/j.apenergy.2016.06.010
0306-2619/

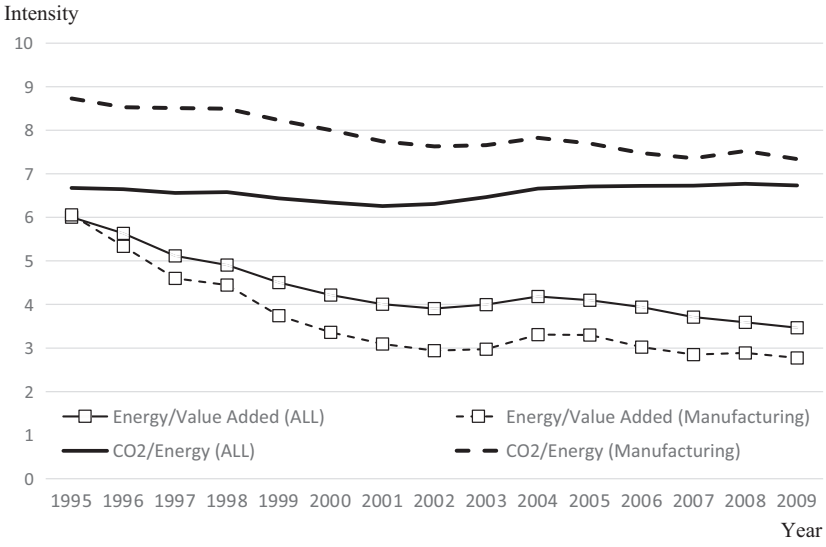

Fig. 1. Carbon and energy-intensity trends in China. Note 1: Unit of value added per energy is millions of yuan per TJ. Note 2: Unit of CO_2 emissions per energy is 100 ton-CO_2 per TJ. Note 3: Value added is deflated to 2005 prices.

to 2009. Energy consumption related to VA decreased from 1995 to 2000 primarily because of the modernization of production equipment in the industrial sector [2]. Although both of these levels increased from 2000 to 2005, they decreased again after 2005. Additionally, CO_2 emissions related to energy consumption in China did not significantly change, although they did decrease annually in the manufacturing sector. This trend indicates that in recent years, the Chinese manufacturing sector has utilized a lower amount of carbon energy.

As the world's largest CO_2 emitter [3], China is the key player in the field of climate change. The primary driver of its emissions is the industrial sector, including manufacturing [4]. The Chinese government is attempting to reduce CO_2 emissions by promoting renewable energy investment [5]. However, the CO_2 emissions-reduction effect is limited by the government's focus on shifting to renewable energy sources because in 2010, the share of emissions produced by primary energy was only 8.3% [6]. Simultaneously, both energy efficiency and energy generation in the manufacturing sector are important for reducing CO_2 emissions [7]. The manufacturing sector's CO_2 emissions are primarily generated by fossil-fuel combustion. Therefore, the CO_2 emissions produced by manufacturing firms reflect both their energy efficiency and their total energy consumption.

The political targets and energy-saving activities of China's eleventh Five Year Plan are the primary reasons for the manufacturing sector's improvements in energy intensity and carbon intensity [8]. The six policy orientations of China's eleventh Five Year Plan included the following: (1) conserving resources and protecting the environment and (2) enhancing capability for independent innovation. Additionally, there were nine major objectives based on these policy orientations, including the following: (1) significantly increasing resource utilization efficiency and (2) enhancing sustainable development. Both of those objectives focus on efficient energy consumption and greenhouse gas (GHG) reduction [9]. These clear political targets provide incentives for local governments and decision makers in manufacturing firms to promote energy saving and GHG-reduction activities [10]. To achieve its nine major energy-saving objectives, China's eleventh Five Year Plan outlined specific activities: (1) ten key projects, (2) energy conservation planning for the top 1000 enterprises, and (3) closing inefficient small-unit power plants [11].

Many scholars are interested in the policies of the eleventh Five Year Plan because of their impressive results in terms of both economic development and energy savings. However, most previous studies on economic development and energy savings during China's eleventh Five Year Plan have used provincial data or industrial data [4,12,13], whereas research relying on corporate firm-level data remains scarce [11,14]. Our primary concern is that the firm-level industrial or regional characteristics that we intend to reveal might be both numerous and heterogeneous [15].

Firm-level ex post studies are lacking because energy consumption data for Chinese firms are not included in the well-known National Bureau of Statistics above-standard firm survey database; nor are they generally available. Although the 1000 enterprises conservation project has provided the National Development and Reform Commission with detailed energy consumption information, these data are not available to researchers. In general, it is difficult to collect firm-level energy consumption and CO_2 emissions data in China. That said, because energy procurement strongly affects production costs, each firm's business managers both determine the amount of energy used and select the energy source. Thus, each firm's energy-use data reflect its corporate strategy, which includes external factors such as environmental policies and energy prices. In this sense, we believe that it is important to focus on changes in corporate financial and environmental performance to understand the impact of China's eleventh Five Year Plan.

Additionally, industrial characteristics affect the relationship between CO_2 emissions and corporate financial performance because the technical difficulty of reducing CO_2 emissions varies across industries [16]. Furthermore, the capital equipment and labor requirements for reducing CO_2 emissions vary across industries because the types of fuel consumed as intermediate materials also vary [17]. Therefore, industrial characteristics provide important information for creating effective energy saving and CO_2 reduction policies in each industry.

Based on this background, we utilized a unique firm-level dataset on financial and environmental performance changes from 2005 to 2009 to conduct an ex post evaluation of the eleventh Five Year Plan. We focus on the characteristics of manufacturing firms that are identified as technical innovators. We examine the corporate financial and CO_2 emissions data collected along with a unique

Please cite this article in press as: Fujii H et al. Firm-level environmentally sensitive productivity and innovation in China. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2016.06.010