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Will technology advances alleviate climate change? Dual effects of technology change on aggregate carbon dioxide emissions

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ABSTRACT

The relationship between technology change and carbon dioxide emissions is complex. Existing research has emphasized technology progress in reducing carbon emission intensity but has ignored the impact of technology progress on economic growth, which leads to changes in carbon dioxide emissions. We argue that technology has relatively independent economic and environmental attributes. To provide evidence for this, we developed a method to distinguish the scale effect of technology change and its influence on economic scale from the intensity effect of technology change and its influence on carbon emission intensity. We applied this method to study the impact of technology change on carbon dioxide emissions in 95 countries between 1996 and 2007. We found that technology change indeed reduced aggregate carbon dioxide emissions, but the scale and intensity effects of technology change separately expressed positive and negative values. As a consequence, previous studies that only consider the intensity effect overestimate the impact of technology change on carbon dioxide emissions. Our findings yield important considerations for carbon dioxide emissions control in policy making.

Introduction

Climate change has become a global concern. Reducing aggregate CO_2 emissions to alleviate global warming is a core priority in addressing climate change. There are two ways to achieve reductions in CO_2 emissions from economic activities: lowering the amount of CO_2 generation in production activities and end-of-pipe control of CO_2 emissions. End-of-pipe control of CO_2 emissions mainly depends on Carbon Capture and Storage (CCS), but CCS technology is facing a lot of problems such as engineering practice and public acceptance (Webley, 2014; Chen et al., 2015), it is still in its experimental stages and comes at a high cost (Nykvist, 2013; Scott, 2013). Consequently, the reduction of CO_2 emissions through end-of-pipe control is limited (Li et al., 2013). Hindering CO_2 generation in production activities is the main approach to reduce aggregate CO_2 emissions.

Technology change can influence the amount of CO_2 generation in production activities. At present, it is widely recognized the role of technology progress in CO_2 emissions reduction. Not only do all countries of the world emphasize lowering CO_2 emissions depending on technology progress, but also international societies like the United Nations (UN) appeal for the transfer of advanced technology from developed countries to developing countries in order to assist in the mitigation of climate change (De Coninck and Sagar, 2015; UNFCCC, 2015; Zhang and Yan, 2015) and the international cooperation of technology development in order to control climate change together (El-Sayed and Rubio, 2014; Ockwell et al., 2015; Rubio, 2016). Therefore, a scaled-up R&D funding is invested in technology development to mitigate climate change (Wiesenthal et al., 2012). A great deal of research evaluated the impacts of some specific technologies on CO_2 emissions from micro perspective, especially energy conservation and low carbon technologies such as renewable energy technologies, and found dramatic CO_2 emissions reduction effects (Kalt and Kranzl, 2011; Albino et al., 2014; Zhang et al., 2014; Pavić et al., 2016; Tokimatsu et al., 2016). It seems that technology progress is sure to lower aggregate CO_2 emissions. Nonetheless, an obvious fact is that aggregate CO_2 emissions has dramatically increased since industrial revolution (Boden et al., 2015), along with the similarly dramatic progress in technology (Fig. 1). Every tremendous progress in technology in modern society, not only brought about the improvements in energy and environmental efficiency, but also greatly stimulated the development of economy and the corresponding energy consumption, which is known as the "rebound effect" (Hertwich, 2005; Herring and Roy, 2007; Sorrell, 2007; Sorrell and Dimitropoulos, 2008; Sorrell et al., 2009; Grant et al., 2016; Lin and Zhao, 2016; Vivanco et al., 2016; Wei and Liu, 2017). Some interesting questions arise: although the development of some low carbon

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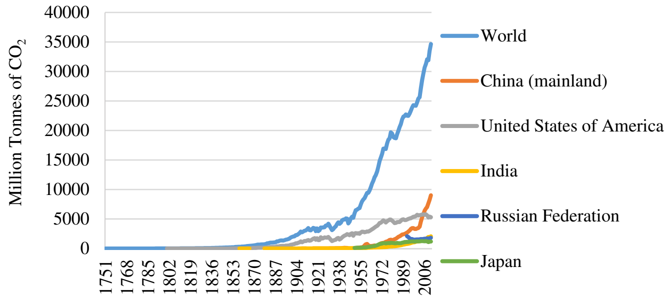

Fig. 1. Global and major national CO_2 emissions.

technologies can lower CO_2 emissions, how will technology development influence aggregate CO_2 emissions from macro perspective? Will technology development indeed lower aggregate CO_2 emissions?

Generally speaking, technology improvement driven by R&D activities can promote amelioration of an economic development pattern, adjustment of an energy structure, and the upgrading of an industrial structure, thus effectively reducing CO_2 emissions per unit of gross domestic product (GDP) (Grubb, 2004; Barrett, 2006; Edmonds et al., 2007; Fischer and Newell, 2008; Bosetti et al., 2009). On the other hand, technology improvement plays an important role in promoting economic growth (Romer, 1990; Grossman and Helpman, 1991; Hu et al., 2005; Wang, 2007; Clarke et al., 2008; Allen, 2012; Bhattacharya et al., 2015), countries and firms generally pay attention to their R&D activities and increase their R&D expenditures for technology innovation so that promote economic growth (C.H. Wang et al., 2013; D.H.M. Wang et al., 2013; Sánchez and Maldonado, 2015). However, technology improvement increases aggregate CO_2 emissions by increasing the economic scale. Current research in the fields of economy and environment have separately investigated the effect of technology change on economic growth and on the reduction in carbon emission intensity; however, studies have not combined the two aspects to comprehensively analyze the overall impact of technology change on aggregate CO_2 emissions. A detailed analysis of the positive role of technology change in decreasing aggregate CO_2 emissions by lowering carbon emission intensity and its negative role, which leads to increasing aggregate CO_2 emissions due to increases in the scale of economic output, would help us better understand the overall impact of technology change on aggregate CO_2 emissions. How we integrate the two aspects into an analytical framework to comprehensively evaluate the dual effects of technology change on aggregate CO_2 emissions is an important subject to be settled. To address these knowledge gaps, we developed a decomposition model that combines the positive and negative roles of technology change in order to not only evaluate the overall impact but also investigate the impact pathways of technology change on aggregate CO_2 emissions.

Existing studies on the influence of technology change on pollutant (CO_2) emissions from macro perspective can be divided into three categories: research to identify the factors affecting pollution emissions based on decomposition analysis, which decomposes pollutant emission change into various coordinate effects (scale effect, technology effect and so on), of which the technology effect was evaluated by using the change in carbon emission intensity as technology change (Grossman and Krueger, 1995; Antweiler et al., 2001; Luukkanen and Kaivo-oja, 2002; Stern, 2002; Wang et al., 2005; Wu et al., 2005; Liu, 2007; Zhang et al., 2009); research using a total factor productivity index as technology change to construct an econometric model or decomposition model to analyze the influence of technology change on aggregate CO_2 emissions (Pasurka, 2006; Zhou and Ang, 2008; Li, 2010); and research using scenarios about the impact of technology change on aggregate CO_2 emissions and using indexes, such as the change in carbon emission intensity, as technology change (Kemfert and Truong, 2007; Steckel et al., 2011; Astrom et al., 2013; Serrenho et al., 2014). Such research has focused on the impact of technology change on carbon emission intensity but has ignored that technology change can promote economic scale, which leads to increased CO_2 emissions. Although the second category of research has combined the economic and environmental elements into a comprehensive analytical framework, these studies calculated the productivity change based on technologies with some pre-assumptions. Pasurka (2006) calculated productivity change based on output distance function which treated good and bad outputs symmetrically (Färe et al., 1986); Chung et al. (1997) and Färe et al. (2001) calculated productivity change based on directional distance function which treated good and bad outputs asymmetrically. As a result, the previous research treated technology with an economic attribute (which affects economic scale) and an environmental attribute (which affects carbon emission intensity) intertwined and the same. However, they are relatively independent and different in reality. For example, environmentally friendly technology progress can result in greater reduction of carbon emission intensity when compared with an increase in the economic scale. Therefore, these studies had analytical bias. Furthermore, these studies could not identify the dual effects of technology change on aggregate CO_2 emissions.

The remainder of this paper is organized as follows: Methodology section presents the models for studying the impact of technology change on aggregate CO_2 emissions. Empirical analysis section provides an application of the models to 95 countries between 1996 and 2007 and discusses the empirical results, and Conclusion section concludes.

Methodology

Dual effects model

Technology change can affect CO_2 emissions in two ways: it can cause an increase in the scale of economic output, resulting in an increase in aggregate CO_2 emissions, or it can reduce carbon emission intensity, resulting in lower aggregate CO_2 emissions. Here, the change in aggregate CO_2 emissions influenced by the change to the scale of economic output resulting from technology change is called the scale effect of technology change, while the change in aggregate CO_2 emissions caused by the change in carbon emission intensity is called the intensity effect of technology change. Any technology advancement will have implications for both. In this research we analyze the dual effects of the intensity of technology change and the scale of technology change on aggregate CO_2 emissions (Fig. 2). Different from existing research, which viewed the economic attribute and environmental attribute of technology are the same, this paper deems that technology with an economic attribute and technology with an environmental attribute are relatively independent; this causes asynchronization between the scale effect and the intensity effect. For this reason, it is necessary to separately study the impacts of technology change on increasing the economic output scale and reducing carbon emission intensity and then to investigate the combined effects of technology change on aggregate CO_2 emissions.

Based on a decomposition model, we constructed a quantity model to analyze the impact of technology change on aggregate CO_2 emissions.

Aggregate CO_2 emissions were expressed as follows:

$$E = I \times Y, \quad (1)$$

where E represents aggregate CO_2 emissions; $I = E/Y$ is the carbon emission intensity, which denotes technology with an environmental attribute; and Y represents economic output.

The change in aggregate CO_2 emissions from year t to $t+1$ can then be expressed by.

$$\Delta E = \Delta I \times Y + I \times \Delta Y + \Delta I \times \Delta Y, \quad (2)$$