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Innovation performance and influencing factors of low-carbon technological innovation under the global value chain: A case of Chinese manufacturing industry

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ABSTRACT

Combing the global value chain framework and linear innovation process model, this paper analyzes the innovation performance of low-carbon technological innovation activities under the global value chain and the influencing factors. Other than previous research on sustainable technological innovation with major focus on radical innovation and socio-technical system transitions activities, this paper places focus on the general innovation characteristics of low-carbon technologies through an integrating view of global value chain and linear innovation process. This paper proposes an analytical framework of the linear innovation process under the global value chain, and uses factor analysis and a DEA-Tobit two-stage method to analyze the low-carbon technological innovation performance and its influencing factors of China's manufacturing industry under global value chain. The results show that the low-carbon technological innovation performance is diverse across different manufacturing industries in China. Moreover, among the three major influencing factors, government regulation is the only factor that shows a positive influence on low-carbon technological innovation performance, yet the effect is quite weak. Technology push displays a negative effect, and the impact of market pull on low-carbon technological innovation performance is not significant.

1. Introduction

The term of Low-carbon Technological Innovation has been increasingly used in recent innovation researches concerning environmental-friendly technologies, such as researches on low-carbon technologies of manufacturing industries (Bi and Wang, 2014; Bi et al., 2015) and marine renewable energy technologies (MacGillivray et al., 2014), which shares a great amount of similarities with the concept of eco-innovation (Rennings, 2000) and technological change (Löschel, 2002). Considering that the carbon-based socio-technical system is possibly the biggest socio-technical system in the history, technological innovation aiming for carbon reduction might lead to a complete transformation of the carbon-based socio-technical system (Jacobsson and Bergek, 2004), which requires system innovation and transitions. Following the major viewpoint, innovation scholars placed great attentions to innovation activities such as radical innovation of low-carbon technology (Bergek et al., 2008; Hekkert et al., 2007) and socio-technical system innovation and transitions (Geels, 2002; Geels and Schot, 2007; Smith et al., 2010). However, incremental innovation activities of carbon reduction technologies have been largely neglected in the mainstream of low-carbon innovation scholarship.

To uncover the general innovation characteristics of low-carbon technologies, turning back to the essence of innovation elaborated in Schumpeter's Innovation Theory, in this paper we view low-carbon technological innovation as innovation activities that not only increase in outputs without increases in productive inputs, but also enhance energy-efficiency and lowers carbon emission intensity through "product innovations, i.e., higher energy-efficiency of existing and new products, and process innovations, i.e., higher energy-efficiency of manufacturing processes, cost reductions in low-emission energy conversion and improvements in fossil energy conversion" (Löschel, 2002: p.105).

Following Schumpeter's conceptualization, innovation is generally viewed as a three-stage process, consisting of invention, innovation, and diffusion (Schumpeter, 1934). Based on the linear innovation model, Stern (2007) proposed a new innovation model for climate change related technologies that included policy intervention and investment activity, which aimed to investigate the general

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characteristics and innovation process of climate adaptation technologies. Thus, in this paper we use the expanded linear innovation model as an instrument to investigate the innovation performance and influencing factors of low-carbon technological innovation.

Ever since the announcement of UK Energy White Paper 'Our energy future - creating a low carbon economy' in 2003, the majority of low-carbon technological innovation research focused on emerging technologies and industries, such as wind power (Gosens and Lu, 2013), solar photovoltaic (PV) (Klitkou and Coenen, 2013), biomass (Breukers et al., 2014), carbon capture and storage (CCS) (Van Alphen et al., 2010) etc. Meanwhile, innovation activities that seek to improve energy efficiency and reduce carbon emission in traditional manufacturing industries also saw an explicit growth. However, just a few innovation scholars had focused on low-carbon innovation in manufacturing industries (Bi et al., 2015; Uyarra et al., 2016). In fact, manufacturing industry accounts for a large amount of carbon emission, especially for newly industrializing economies.

Taking China for example, manufacturing industry accounted for 47% of the total carbon emission in 2012 (Liu, 2015). In the meantime, a strategic plan called 'Made in China 2025' that was released by the Central Government of China in 2015 has proposed an ambitious carbon reduction target for China's manufacturing industry: compared to 2015, energy consumption and CO_2 emission per unit of added value for large-scale industrial enterprises dropped by a total of 18% and 22% respectively. On the other hand, China's manufacturing industry also acts as the main pillar of economic growth and employment opportunities. It is fair to say that manufacturing industry in China is facing dual pressures of carbon emission reduction and sustainable economic development. This leads to the question that how China's manufacturing industry could achieve low-carbon transition and sustainable development at the same time?

Since China became a member of World Trade Organization (WTO) in 2001, China's manufacturing industry began to get involved in the global value chain. And just in a short period of time, China became the 'world factory' with huge trade surplus. The term Global Value Chain (GVC) was first proposed by Gereffi and Korzeniewicz (1994), and thereafter has been widely used by major scholars in this field. The United Nations Industrial Development Organization (UNIDO) defined GVC as a global cross-enterprise network that realizes the value of goods or services, which links production, sales, recycling and other processes (UNIDO, 2003).

Accompanying with increasing economic globalization and international labor division, GVC governance begins to play a more and more important role in manufacturing development and upgrading (Gereffi et al., 2005; Humphrey and Schmitz, 2002), especially for emerging and developing economics such as China that are still at the stage of low added-value production or assembly activities. The 'low-end locking' issue for China's manufacturing industry is believed to be the consequence of monopoly of a few global enterprises on high added-value activities such as R&D of key technologies, and brand marketing (Morrison et al., 2008). In the meantime, emerging low-carbon economy at global scale is urging for a low-carbon transformation of traditional manufacturing industries with high energy consumption and pollution emission. This represents both opportunity and challenge for China's manufacturing industry to break the 'low-end locking', and to achieve low-carbon upgrading in the GVC. In this context, stimulating low-carbon technological innovation activities in China's manufacturing industry is viewed as a fundamental solution (Chiarolla, 2008). The key role of low-carbon technological innovation has also been justified in case studies of both developed and developing countries (Henriques et al., 2010; Park et al., 2009).

Thus, in this paper we analyzed the innovation performance and influencing factors of low-carbon technological innovation of China's manufacturing industry under the GVC, and provided a few policy implications for Chinese government to stimulate low-carbon upgrading of China's manufacturing industry. The structure of the paper is as follows: firstly, we integrated the linear innovation model and GVC framework together as the analytical framework to investigate innovation performance and influencing factors of low-carbon technological innovation activities in manufacturing industry. Secondly, using factor analysis and a DEA-Tobit two-stage method, the low-carbon technological innovation performance and its influencing factors were evaluated and analyzed. At last, we proposed several policy implications based on empirical analysis results.

2. Theoretical framework

The GVC framework has been widely used to investigate the dynamics of technology development under the globalization (Bi et al., 2015; Kiamehr, in press; Pietrobelli and Puppato, 2016). For our case study of Chinese manufacturing industry, every component of Chinese manufacturing industries is highly embedded in the GVC, especially with regard to low-carbon R&D, manufacturing, and marketing activities. When it comes to low-carbon technologies, transnational technology transfer and secondary innovation play a much more important role in China (Zhang and Gallagher, 2016). Moreover, GVC as a framework can bring domestic innovation activities and global governance together, which emphasizes the interaction between domestic manufacturers and the global production network (Pietrobelli and Rabellotti, 2011). The GVC framework is able to lead us to a better understanding of the exchange of technical knowledge, market information, and feedback in the innovation process. Thus, combing the GVC framework into innovation process analysis is necessary for us to observe each stage of innovation processes under the governance of the GVC. This is especially essential for an emerging economy like China, which to some extent can avoid the misleading to overestimation of Chinese innovation capacity that tends to overlook the major role of foreign technology import.

2.1. The value creation process under the GVC

As a chain that links production, sales, recycling and other processes, GVC involves various value creation activities including design, product development, manufacturing, marketing, after-sales service and recycling (UNIDO, 2003). KaPlinsky and Morris (2001) singled out four elements of a value chain, constituting design and product development, production, marketing, as well as consumption and recycling. They also categorized design and product development and marketing as strategic value elements, which are able to create higher added-value in the GVC. On the other hand, manufacturing is viewed as low added-value activities. The difference of value creation capacity of elements along the GVC forms a U-shaped curve, which is vividly named as 'smile curve' (Mudambi, 2007). In this paper, we focus on three major elements of the GVC: research and development (R&D), manufacturing, and marketing.

2.2. The linear process of low-carbon technological innovation under the GVC

The linear innovation model proposed by Kline and Rosenberg (1986) argued that innovation was a linear process involving research, development, manufacturing, and marketing activities. It is generally accepted that R&D, manufacturing, and marketing are the key stages of innovation process. Moreover, a few innovation scholars have placed the linear innovation process under the GVC. Schmitz (2004) argued that manufacturers in the developed countries have always been the main actors of innovation activities under the GVC, even though manufacturers from developing countries begin to gain more market share. For manufacturers in developing countries, getting involved in the GVC does not necessarily translate into higher innovation performance. Even though most of incremental innovation activities can be conducted by 'learning by doing', it still requires a certain level of learning capacity (Morrison et al., 2008; Pietrobelli and Rabellotti, 2011).