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Dynamic study on the influencing factors of industrial firm's carbon footprint

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ABSTRACT

Industrial firms are central to the effort to grapple with emission of greenhouse gases due to large material flows they process. Thus, employing system dynamics approach, the present study explored influencing factors of industrial firms' carbon footprint. Using empirical data from selected firms in China, simulation results revealed that price of raw material; governmental subsidy and pressure from international rules, as well as firm's awareness of social responsibility have slightly affected firms' carbon emissions. On the contrary, some factors have obvious effects on firms' carbon footprint including governmental regulation, awareness of consumer, company size, the ratio of low carbon package and recycling.

1. Introduction

Industrial firms are central to paving the way toward a low-carbon society, because a large portion of carbon inputs and GHG emissions stems from industrial production (Hoffmann and Busch, 2008). This is especially relevant in China, the world's largest consumer of energy and emitter of CO2. Between 1992 and 2007 the rapid development of industry in China led annual total industrial CO2 emissions to grow by 166%, almost 3992 million t (Minx et al., 2011). In 2009, the most CO2 emissions industry was petroleum processing, which reached 2672 million t (He and Zhang, 2012). The most pressing off-target performance is the drastic increase in industrial-based CO2 emissions, which accounted for 80% of total CO2 emissions in China (Pan et al., 2011). Fortunately, China has committed that by 2020 it will reduce its CO2 emissions per unit of GDP by 40–45% from 2005 levels and use non-fossil fuels for about 15% of its energy. This has forced industrial firms to take action to carry out carbon footprint management and mitigate greenhouse gas emissions from their operations, as well as emissions stemming from their products and services. However, industrial firms' carbon footprint has been influenced by many factors, such as production technology, market pressure and governmental regulation etc. In order to manage industrial firms' carbon footprint while achieving better environmental objectives, alternative approaches could be taken. But the difficulty is in knowing whether the alternative approaches are effective and getting firms to respond predictably to these alternatives. Therefore, it is important to identify the influence factors of firms' carbon footprint. To date carbon footprints have been established for countries and sub-national regions (Hertwich and Peters, 2009), institutions (GAP et al., 2006), products (Carbon Trust, 2006), businesses and investment funds (Trucost, 2006). But until recently there has been a lack of data and resources to dynamic study the influencing factors of firms' carbon footprint. Therefore, the aim of the present study is to explore this issue. The results will provide a promising basis for decision-making to support firms' carbon management, gaining competitive advantage (Yang et al., 2013) and governmental policy-making.

2. Literature review

The carbon footprint (CFP) is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product (Wiedmann and Minx, 2007). CFP is a footprint that measures CO2 or other greenhouse gas emissions. As happens with ecological footprint, this indicator can be applied to companies and organizations, with the concepts of corporate carbon footprint being a very attractive indicator at this level. Firms' carbon footprint has already been the focus of a great deal of researches. Three such themes could be identified in the literature and are discussed below.

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The first research stream focused on the calculation of firms' carbon footprint. Different approaches have been used to estimate firms' carbon footprint, which can be approached methodologically from two different directions: bottom-up, or top-down, for example, life-cycle assessment (Lenzen, 2001; Suh et al., 2004). Meanwhile, according to the research of, input–output analysis is capable of capturing emissions from the entire supply chain, and can be used as a screening tool to inform estimation of the anticipated life-cycle emissions, which supported the findings of Minx et al. (2008). Other interesting methods also have been employed, such as Triple-Bottom-Line Accounting Approach (Wiedmann and Lenzen, 2007), the method composed of financial accounts (Penela et al., 2009). Although Hertwich and Peters (2009) believed that it is most appropriately calculated using life-cycle assessment or input–output analysis, there is still no consensus regarding certain matters that determine its content (the inclusion of CO2 or other gas emissions), scope (direct emissions or indirect emissions, being embodied in the purchase of goods and services that need energy in their production), and methodology.

The second research stream that has emerged in the literature focuses on influence factors. For example, Garbuzova and Madlener (2012) analyzed the opportunities and barriers for foreign companies in the Russian energy market. In China, five potential influencing factors to implementing CO2 capture ready are identified by Li et al. (2012), such as rigid land control etc. Vickers et al. (2009) identified many external factors that face small and medium-sized enterprises wishing to adopt low carbon production, such as non-existent or limited green consumer demand, lack of an organizational network supporting environmental activities, and limited infrastructure supporting management. Meanwhile, Okereke (2007) conducted an empirical case study of 100 companies and found numerous existing barriers to corporate activity related to climate change in the UK, such as uncertainty about government actions. However, in Switzerland, Engau and Hoffmann (2009) concluded that improving the mechanisms by which firms participated in the early stages of policy making could enable them to become more target-oriented and allow more efficient post-Kyoto policy implementation.

Numerous internal factors have also been identified. Internal factors frequently mentioned in the previous literature include lack of "awareness of the environmental impacts of a firm's activities on the part of owner-managers", "poor management skills", and "a lack of strategic awareness" (Vickers et al., 2009), as well as "limited innovation capacity" (Zhou et al., 2012). Although capacity has emerged as a critical precursor to action (Yohe and Tol, 2002), some studies have suggested that psychological factors (such as perceived adaptive capacity (Grothmann and Patt, 2005), and the normative or motivational context of responses) were more important than resource constraints (Haddad, 2005). Rather than focusing on technologies, it has been argued that only deeper underlying path-dependent development trajectories can reveal the true sources of factors to action (Burch and Robinson, 2007). This view is partly supported by Vickers et al. (2009), who found that some recent contributions have warned against over-emphasizing new technology as a solution to climate change, drawing attention instead to the need for behavioral change among both businesses and consumers.

As can be seen from this literature review, the influencing factors of firms' carbon footprint are complex and there is interaction among government, consumer, and community. These aspects have been studied to a limited extent. It is very difficult to analyze the dynamically changing situation involving heterogeneous subjects by employing traditional static, homogeneous methods. Thus, to fill this gap, the present paper employed a system dynamic model to explore the dynamics of the influencing factors on firms' carbon footprint.

3. System dynamics model

The SD methodology, which is adopted in this research, is a modeling and simulation technique specifically designed for long-term, chronic, dynamic management problems. SD differs significantly from a traditional simulation method, such as discrete-event simulation where the most important modeling issue is a point-by-point match between the model behavior and the real behavior. Rather, for an SD model it is important to produce the major "dynamic patterns" of concern. Thus, it is evident that the modeling methodology that will be employed needs to be able to capture the main influencing factors of industrial firm's carbon footprint. SD has this capacity and moreover, it easily describes the dynamic evolvement of the influencing factors. The SD methodology has been employed successfully in many research fields (Aristidou et al., 2013; Mukherjee et al., 2013; Guo and Dai, 2014).

3.1. Theoretical framework

The concept of a carbon footprint captures the interest of businesses, consumers, and policy makers alike. First, governments are under growing pressure to enact legislation to curb the amount of carbon emissions (Benjaafar et al., 2013). Researchers have argued that governmental regulations are the main factors influencing environmental behavior of firms, such as Reijnders (2003) found regulation through permits based on adequate rules and related negotiated agreements might emerge as more specific instruments improving clean production, which supported the findings of Wang et al. (2007) and Xu and Luan (2004) in China.

Besides pressure from governmental regulations, many other studies have shown that the pressure from markets also affects the environmental behavior of firms (Weber, 1990; Bermmer, 1989). Purchasing managers are curious about the carbon footprint of their supply chains, and consumers are increasingly offered carbon-labeled products (Lash and Wellington, 2007). However, in mainland China, based on the research of Wang et al. (2007), the pressure from markets, especially the pressure from domestic markets have not been the main pressures on industrial firms. Another research stream that has emerged in the literature focuses on communities, which are playing a more active role in environmental protection in developed countries and have become a key factor in determining environmental behavior of firms (Chen and Soyez, 2003). In China, some communities are playing positive roles in engaging firms to improve their environmental performance (Zhang et al., 2008). However, they were not found to be the key factor determining environmental behavior of firms in China (Cai, 2002).

This theoretical framework indicated some interaction influencing factors, such as governmental regulations, market pressure and consumers' behavior, as well as communities, which provide predictions of the dynamic relationship between influencing factors and firms' behavior. Therefore, the theory yields these relationships between different factors. The SD model and empirical research which were followed could be viewed as an estimation of these hypotheses.

3.2. Model description

A key characteristic for a firm's carbon footprint is the number of phases from raw materials to the end user. Moreover, it also includes products' end of life phase, for example, land fill or recycle, and administration of a firm (Fig. 1). The present study focuses on a

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