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Policy and innovation: Nanoenergy technology in the USA and China

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HIGHLIGHTS

- We compare development status of nanoenergy technologies between China and the USA.
- We mainly focus on their policies, innovation performance and pattern in nanoenergy.
- Differences are observed in nanoenergy technologies developed in these two countries.
- We propose their endeavor directions in nanoenergy based on this study.

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ABSTRACT

The USA is a leading country while China is an up-and-coming one in nanotechnology. We carried out a cross-country comparative study on policy and innovation of the two countries in subset nanoenergy field. They both created favorable policy environments for nanotechnology involving applications of nanotechnology in the energy sector. However, Chinese policy deployments for nanotechnology lack coordinated arrangements and effective assessment mechanisms. China performs better than the USA in technological quantity, but weaker in technological influence. The USA expresses an industry-oriented model in nanoenergy technological research and development, but China exhibits a university-and-institute-oriented model. Interorganizational collaboration relationships in the two countries are both still very rare and have huge development space. They both have a long way to go in converting their technological achievements into commercial products, especially China. Finally, we provide the policy implications of this study. In particular, the Chinese government should strengthen its efforts in policies by changing the national S&T evaluation system to set up the basic idea that quality is better than quantity in order to raise the original innovation motivations of innovators.

1. Introduction

Nanotechnology is a type of general-purpose and enabling technology and it has penetrated into various fields and integrated them nowadays (Fisher and Mahajan, 2006; Islam and Miyazaki, 2010; Mangematin and Walsh, 2012). Since 1990s, considerable progress has been achieved in nanotechnology, and it became one of the most active and promising areas in the 21st century (Gorjiara and Baldock, 2014; Hullmann, 2007). Widespread applications of nanotechnology and tremendous progress in it have sparked technological breakthroughs in many fields, such as medical and health, energy and environment, water, information and safety, materials and biology and so on (Fisher and Mahajan, 2006; Rejeski, 2009; Roco, 2011). These breakthroughs exert a far-reaching influence on economic and social developments.

Applications of nanotechnology in the energy sector involve the conventional and renewable energy, especially the latter (Luther, 2008; Invernizzi et al., 2015). These applications exhibit a vast growth recently and derive out a promising emerging field – nanoenergy (Guan and Liu, 2014, 2015, 2016). This is because, on the one hand, that fossil energy is not only short in supply but also its consumption discharges a mass of pollutants; on the other hand, that the commercial scale of renewable energy is difficult to realize nowadays (Invernizzi et al., 2015; Guan and Liu, 2014). Nanoenergy technology is the applications of nanotechnology in both the conventional and renewable energy sectors (Luther, 2008). Thus, it is an interdisciplinary field at the intersection of nanotechnology and energy technology. Nanoenergy technology

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presents a huge potential for development. Extant studies have shown that nanotechnology offers great opportunities to develop and improve every phase of the entire energy value chain, including sources, conversion, distribution, storage and also final usage of energy (De Souza and Leite, 2012; Guan and Liu, 2015; Luther, 2008; Mangematin and Walsh, 2012; Guan and Liu, 2016). Below, we give several examples about nanoenergy technology. Some possible applications of nanotechnology in fossil fuels are wear and corrosion protection of oil and gas drilling equipment; in nuclear energy are nano-composites for radiation shielding and protection; in renewable energy are hydrogen membranes and storage, nano-optimized cells, super conducting cables based on carbon nanotubes, and wires capable of more efficient energy distribution and so on (Luther, 2008; NSTC et al., 2014; Hussein, 2015). Energy shortage and environmental issues are both becoming increasingly prominent today. Nanotechnology is expected to dominate future development of energy under the urgent situations (Tegart, 2009; Guan and Liu, 2015).

Many scholars are interested in efforts done by the USA and China and also some other countries in nanotechnology, because opportunities and challenges of countries in this field will imply their competitive advantages in the future. Many studies were carried out on countries' status in nanotechnology. For instance, Guan and Ma (2007) compared the publication activity of China in nanotechnology with that of the USA and also some other 'giant' countries. Kostoff (2008, 2012) investigated science and technological performance of the USA and China in nanotechnology. Appelbaum and Parker (2008) explored the recent efforts done by China from fundamental research to the incubation of commercial products in nanotechnology. Jung and Lee (2014) examined the impacts of the USA's National Nanotechnology Initiative (NNI) on the nature of university research in nanotechnology by using a difference-in-difference analysis method. Walsh (2014) measured the contributions of foreign-born scientists and engineers on nanoscience research in the USA. In order to assess nanotechnology structures in China and Japan, Baglieri et al. (2014) compared their nano-patent landscapes through mainly focusing on technology policy and a subset of nanotechnology. Guo et al. (2015) compared patterns between China and the USA in nano-enhanced drug delivery. Previous studies indeed provide us with a general landscape of the efforts of the USA and China in nanotechnology, but they lack access to detailed information about the promising emerging field – nanoenergy. Because, existing studies mainly focused on either the total nanotechnology field or some other subset field of it, no one has done a comparative analysis on the specific nanoenergy technology between the USA and China. Considering the importance of nanoenergy under the current urgent situation, we therefore tend to examine comparative patterns between the USA and China in nanoenergy technology through focusing on policies and unique nanoenergy patents data.

To be specific, in order to learn efforts done by the governments of the USA and China and also innovative landscapes of the two countries in nanoenergy technology, we carried out a fully comparative analysis in this study. Through performing the comparative investigation, we expected to promote relevant policies and strategic positioning of the two countries in the nanoenergy field. To achieve the intended target, we mainly did the following work. Nanotechnology policies were firstly examined by us to find out how roles the USA and Chinese governments did in their roads to become world leaders in nanotechnology. Then, based on nanoenergy patent data extracted from Derwent Innovation Index (DII) database, technological performance and pattern of the two countries in the nanoenergy field were compared by paying close attention to technological capacity, interorganizational collaboration and technological influence. Finally, nanotechnology-based consumer products were compared to learn their commercial progresses.

2. Methods

Nanotechnology policies we explored are the laws, regulations, plans and programs and so on launched by government departments of the USA and China aiming at fostering the development of nanotechnology. We particularly focused on those policies that involve applications of nanotechnology in the energy sector. We paid our attention only to national-level policies because of a wide range of initiatives also pursued by local governments of the two countries. To perform comparative analyses on nanotechnology policies of the USA and China, official websites of their government departments were searched by us to acquire relevant policies we needed. We skimmed the policies we collected and eliminated some ones that seem unrelated to nanotechnology.

To investigate profiles of the USA and China in nanoenergy technology, we performed patent analyses including counting analysis, assignee analysis, co-occurrence analysis and also citation analysis to generate several statistical indicators capturing different aspects of nanoenergy technological activities. We collected nanoenergy patents from DII provided by the Thomson Reuters Corporation. We chose DII because it is one of the most comprehensive patent databases worldwide covering patent information issued by more than 100 countries and 40 patent authorities. Thereby, we can extract all the nanoenergy patents granted to the USA and China patented by different patent authorities. The comparatively overall extracted results can comprehensively reflect technological development situations. We employed a modular keyword searching strategy used by Guan and Liu (2015) to capture nanoenergy patents worldwide (see Appendix A for the specific query terms). To be specific, we firstly adopted some relevant nanotechnology keywords to search titles and abstracts of each patent to acquire nanotechnology patents. Then we used some relevant energy keywords to search titles and abstracts of each patent to obtain energy patents. After the first two steps, a logical AND operation was then performed by us on the searching results of nanotechnology patents and energy patents to capture nanoenergy patents (Guan and Liu, 2014, 2015). This searching strategy can effectively collect nanoenergy patents, because nanoenergy is the intersection of nanotechnology and energy technology.

We performed the retrieval process of nanoenergy patents in October 2014. After thoroughly identifying and cleaning searching results, we finally obtained a sample of over 40,000 nanoenergy patents worldwide during 1991–2013 and 36,000 of them are granted to firms, universities or research institutes. DII database does not provide country information for patentees, which brings inevitable difficulties for a cross-country comparative study. To solve this problem, we manually categorized each of the 36,000 nanoenergy patents into one or more specific countries based on their assignees.

To examine commercial products, we adopted a product inventory available from http://www.nanotechproject.org/cpi/, which covers nanotechnology-based consumer products in the international market. This inventory provided by Woodrow Wilson International Center is comparatively comprehensive and also timely updated. Thus, data collected from it can mirror the commercial activities of a country in nanotechnology in some degree. Bhattacharya et al. (2011) employed it to analyze the Chinese visibility in nanotechnology-based products. We used it to compare the commercial activities of the USA and China in nanotechnology and its subset nanoenergy field.