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Analysis of Russia's biofuel knowledge base: A comparison with Germany and China

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HIGHLIGHTS

- Biofuel knowledge base (KB) of Russia is compared to those of Germany and China.
- Citations network analysis measures KB size, growth, cumulativeness, and interdependence.
- Russian KB lacks the increasing technological specialization of German KB.
- Russia KB lacks the accelerated growth rate of Chinese KB.
- Russia KB evolution reflects the poor institutional framework.

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ABSTRACT

This study assesses the evolutionary trajectory of the knowledge base of Russian biofuel technology compared to that of Germany, one of the successful leaders in adopting renewable energy, and China, an aggressive latecomer at promoting renewable energy. A total of 1797 patents filed in Russia, 8282 in Germany and 20,549 in China were retrieved from the European Patent Office database through 2012. We identify four collectively representative measures of a knowledge base (size, growth, cumulativeness, and interdependence), which are observable from biofuel patent citations. Furthermore, we define the exploratory–exploitative index, which enables us to identify the nature of learning embedded in the knowledge base structure. Our citation network analysis of the biofuel knowledge base trajectory by country, in conjunction with policy milestones, shows that Russia's biofuel knowledge base lacks both the increasing technological specialization of that in Germany and the accelerated growth rate of that in China. The German biofuel citation network shows a well-established knowledge base with increasing connectivity, while China's has grown exceptionally fast but with a sparseness of citations reflecting limited connections to preceding, foundational technologies. We conclude by addressing policy implications as well as limitations of the study and potential topics to explore in future research.

1. Introduction

The trade-off between exploratory and exploitative learning (March, 1991) creates tension from the differential outcomes of the radical versus incremental innovation processes (Freeman and Perez, 1988; Sorensen and Stuart, 2000). Both are essential, since exploration leads to vastly new discoveries while exploitation allows for efficiency improvements (Henderson, 1993). However, both learning types are not essential at the same time, which presents a window for long-run policy to affect innovation outcomes. In the case of environmental innovations, the effect of externalities accumulate over time, potentially locking in unsustainable technologies (Ayres, 1991; Kemp and Soete, 1992). This is the situation facing global learning and innovation processes for renewable energy technologies in response to carbon lock-in (Unruh, 2000), and this has hindered the exploration and development of niche technologies in the formative stage of biofuel development in many countries, namely Russia in this study, delaying the transition to the market expansion stage (Jacobsson and Bergek, 2004).

As environmental innovation has become a must, not an option, Russia, one of the main fossil fuel exporters, also recognized the needs to develop renewable energy, particularly biofuels, which were assessed as having a huge commercial potential with devoted agriculture production, abundant timber resources, and considerable knowledge competencies (Martinot, 1998, 1999; REA,

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2012). However, due to abundant fossil fuel resources[1], developing renewable technologies such as biofuels had not been a part of the economic and political priorities in Russia during the 1990s. While the recent initiatives (e.g. Energy Strategy for 2030 (MERF, 2009)) point to a need for investment in renewable energy as a mechanism for achieving the priority of increasing energy efficiency and diversifying energy sources, a formidable gap still exists between actual progress and proposed development (Kolchinskij, 2008; Martinot, 1998; Pristupa et al., 2010; REA, 2012). During 2006–2007, there were about twenty large biofuel production facilities planned in Russia, including bioethanol, biodiesel, and pellets production (Lykova, 2010). However, only pellets plants were built and operated successfully, leaving other forms of production frozen or uninitiated due to various reasons, among which were the lack of financial investments, institutional support and uncertain demand for biofuels (Lykova, 2010). Even the existing pellet plants are mainly for exports, concentrated in the Northwestern Federal District near the border, where the main customers include Belgium, Denmark, the Netherlands, Germany and Sweden (Lykova, 2010), and the Khabarovsk region, which serves South Korea as its largest customer (INFOBIO, 2013).

While existing studies address the inefficiencies of the Russian government's policies and poor implementation in detail (Martinot, 1998, 1999; Pristupa et al., 2010; Zhang et al., 2011), there has been little quantitative analysis of the influence that policy has on the evolutionary path of Russia's knowledge base and collective abilities to utilize the available resources for commercialization. Without understanding the status quo of its development, policy conclusions or further implications may be misinformed by inadequate misunderstanding of the status quo (Lall, 1992, 2010). Thus, this paper aims to diagnose Russia's biofuel knowledge base, one of the outcomes in the formative stage of renewable energy system which is predominantly influenced by government policies. We particularly analyze the position of Russia's biofuel knowledge relative to Germany, one of successful leaders in adopting renewable energy, and China, an aggressive latecomer at promoting renewable energy. For this purpose, the present study explores relationships between said policies and their consequences upon the evolution of biofuel knowledge base network. The aim is to provide a diagnostic tool for policy makers to direct policy that helps to transition a country from the formative stage of technological system evolution to the market expansion stage for the new technology. Such policy requires accurate assessment of not only the objective but also the current state of affairs informed by quantitative analyses.

This study aligns with the call for literature related to quantitative empirical support of knowledge and social networks research (Breschi and Lissoni, 2005), which, despite the importance of collaborative and knowledge networks for technological innovation, is only sparsely addressed in the literature. In particular, patent citations have been employed as knowledge “flow” indicators (Hu and Jaffe, 2003; Jaffe and Trajtenberg, 1999). A network perspective is important in analyzing this patent citation data because invention is a cumulative and social process, and closer social proximity between inventors has been found to correlate positively with citations between them (Balconi et al., 2004). While both the networks of inventors and patent citations play important roles for technological innovation, quantitative research into the application of network analyses on these relational datasets is still in its infancy (Breschi and Lissoni, 2005). Besides the commonly used network properties of size and growth, we incorporate cumulativeness and interdependence, and we propose the “exploratory–exploitative index,” (called EE index herein) which can enable us to understand the type of learning (on a spectrum between wholly exploratory and completely exploitative) observed from the structure of the patent citations network.

This paper proceeds as follows: Section 2 describes the sources of our data as well as methods adopted to achieve the goals of the study. Section 3 shows where Russia stands compared with a potential benchmark, Germany, and a competitive peer, China, based on the results from various analyses. Section 4 discusses the results in more detail which reveal possible challenges that Russia may confront in the future as well as limitations of the current research connected to suggestions for future work. Finally, we conclude the paper with implications for legislators and practitioners.

2. Methods

2.1. Data

We use biofuel related patents filed within Russia, Germany, and China. We applied a two-stage interactive approach to retrieve patents from the most recent available version of the European Patent Office database with worldwide coverage (EPO, 2013). We retrieved the patents that applied for protection of intellectual property in each of the three countries. We used a Porter stemmer in the SQL query for 90 keywords and 95 International Patent Classification (IPC) groups developed by Hu and Phillips[2] (Hu and Phillips, 2011) for identifying biofuel related patents. To trace the timing of knowledge creation closer to the actual time of invention (Hall et al., 2001), we used patent applications rather than granted patents. As a result, the number of patent applications (called “patents” hereafter) retrieved was 1797 for Russia, 8282 for Germany and 20,549 for China covering the published patent applications until the end of 2012. In this dataset, the earliest patent application happened in 1936 for Russia, 1911 for Germany, and 1953 in China. For citations network analysis we retrieved the information about patents that were cited by biofuel patent applications (outward citations) and information about patents that cited the biofuel patent applications (incoming citations). Not all patents had citations (either outward or incoming), especially in China or Russia, which might be due to the specific patenting procedures in these countries. In total, the citation network analysis included 460 patent citations for Russia, 5017 for Germany and 1831 for China.

As different generations of biofuels convey different meaning about the evolution of the knowledge base, this study further classified patents by generation.[3] We applied a text-mining procedure[4] to a sample[5] of the abstracts of the patents retrieved from the EPO

[1] Russia is the world's second largest oil exporter and the top exporter of natural gas (IEA, 2011).

[2] The full list of keywords and IPC codes can be find in Appendix B-1 and B-2 of Hu and Phillips (2011).

[3] While there can be 3rd and 4th generation, its classification has not reached consensus yet (OECD/IEA, 2011). So far, only 1st generation technologies have achieved commercial scale, thus this study considered up to 2nd generation for which the criterion is based on the type of feedstock.

[4] We developed the training sample for each country separately based on its own patents to control for regional differences, and this training set was manually classified by subject experts. We used a Support Vector Machine (SVM), which is one of the highest accuracy algorithms for automated text categorization (Sebastiani, 2002), implemented in RapidMiner 5.0 (Rapid-I GmbH, 2014) to classify the remaining patents as 1st or 2nd generation biofuels according to the title and abstract texts. Model training set accuracy was 82.11%, which was deemed satisfactory.

[5] The sample for developing of classification was: 220 patents for Russia, 290 patents for Germany, and 300 patents for China. We used 80% as training sample and 20% as validating sample for each dataset and tested it on 8 algorithms showing the range of accuracy from 79.10% to 82.11%, of which SVM was highest.