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Scientific effects of large research infrastructures in China

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ABSTRACT

Large research infrastructures (RIs) are expected to play an important role in the development of scientific activities in China and the construction of China's national scientific systems. However, few studies have been devoted to the systematic evaluation of the scientific effects of China's RIs. This paper attempts to fill this gap by designing a comprehensive analytical framework composed of the input-side, output-side, process-side and environment-side effects of RIs on scientific activities. The analysis is implemented based on a novel sample composed of nine of China's typical RIs. More specifically, this paper classified these nine Chinese RIs into the following three types according to their functions: dedicated research infrastructure, public experimental platform and public infrastructure. Furthermore, this paper analyzes the features of the scientific effects of these RIs in terms of the following four typical scientific effects: science and technology advancement effect, capability cultivation effect, networking effect and clustering effect. In addition to the finding that RIs have promoted scientific advancements in many disciplines in China, the study found that RIs are important to the acquisition of new knowledge, and also contribute to the propagation of competitive scientific organizations and scientific talent. Networking and clustering impacts are also important scientific effects of RIs, as they increase the effectiveness of scientific activities in China. This paper not only contributes to developing an analytical framework for evaluating the functions and effects of large RIs but also presents evidence regarding the development of large RIs in emerging countries.

1. Introduction

Research infrastructures (RIs) have become a topic of interest and priority among funders, political bodies, and (increasingly) institutional decision makers (Lossau, 2012). Currently, with the increasing importance of RIs to science and technology development as well as to enhancing competiveness, the economic and social value of RIs has taken on even greater consequence for both developed and developing countries. Over the last half century, RIs have become an important instrument in the exploration of the frontiers of science and technology, and they have aided in the realization public value and the support of social needs. According to European Commission (2010), RIs are in the center of the knowledge triangle of research, education and innovation and serve as the most important carrier of valuable new knowledge. Thus, both developed and developing countries devote resources to building and updating RIs in scientific frontiers (ESFRI, 2006; Research Councils, 2010; Office of Science, DOE, 2003; CSC, 2013). RIs are expected to endow countries with the capability to produce world-class research to improve economic and social outcomes. In the catching-up situation, the RIs are even more important for emerging countries that want to surpass developed countries in the science and technology fields.

As a country with an emerging scientific and technological presence, China has devoted tremendous efforts to the development of RIs to support innovation-driven development. Consequently, China has played an increasingly important role in the construction and application of RIs around the world since RI construction began in China with the atomic and hydrogen bomb projects and the man-made satellite project. In China, RIs are usually described as large scientific engineering projects that are built primarily under the auspices of the Chinese Academy of Sciences (CAS), which is one of top academic research institutes in China. Due to the need for scientific and technological breakthroughs, as well as the innovation-driven development in China, RIs attract more attention and obtain more investment from the Chinese government than they have in the past. Because of the high cost of RIs and the important role they pay in economic and social development, both policy makers and officials of funding agencies are increasingly relying on formal and systematic evaluation procedures to make key decisions about implementing new projects and programs or about upgrading or even terminating existing projects. In terms of the construction of RIs, scientific effects should be a primary consideration in policy making regarding the development and management of RIs.

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Table 1
Typical definition of RI by administrative department.

Author	Definition
NSF (2013)	Large-scale networking or computational infrastructure, multi-user instruments or networks of such instruments, or other infrastructure, instrumentation and equipment having a major impact on a broad segment of a scientific or engineering discipline.
ESFRI (2011)	Facilities, resources or services of a unique nature that have been identified by European research communities to conduct top-level activities in all fields. Includes the associated human resources and covers major equipment or sets of instruments, in addition to knowledge-containing resources, such as collections, archives and data banks.
CSC (2013)	Large and complex science systems that are expected to provide exceptional research tools for exploring the unknown world, discovering scientific law and realizing technological change.

However, to our knowledge, there are very few relevant studies that evaluate the scientific effects of China's RIs in the existing literature. The processes of identifying, funding, designing, developing, constructing, managing and sharing RIs require an effective assessment of RIs. This research gap should be filled and then a more effective development path should be designed to improve the active function of China's RIs during the building of this innovation-driven nation.

Extant studies evaluating the scientific effects of RIs in developed countries depend primarily on so-called "facility metrics", which combinations of the number of publications, the operations reliability / technical performance, and the user demand for experimental time (Hallonsten, 2014). The sole bibliometric assessment of RIs has several limitations in terms of the expected function of RIs in social and economic development, and extended measures— beyond simple counts of publications, citations and costs—that aid in comprehensively assessing the scientific effects of RIs should be specifically proposed (Heidler and Hallonsten, 2015; Zuijdam et al., 2011; GSF, 2014; CAS, 2007). Consequently, an important goal of this study is to build an analytical framework for evaluating the scientific effects of RIs. The analytical framework can be used to compare and evaluate China's typical RIs and provide valuable evidence that can be useful in improving the operations and management of large RIs. The classification of Chinese RIs according to function in our analytical framework is a new and managerially useful method for comprehensively evaluating RIs. This approach can provide a comprehensive evaluation of the scientific effects of RIs in terms of input-side, output-side, process-side and environment-side impacts on scientific activities. Moreover, our focus on the diversity of RIs and the systematicness of RI effects can aid in developing different policy measures for different RIs and in classifying RIs and types of scientific effects. Our analytical framework can provide a way for policy makers to comprehensively understand the differences in the scientific effects of RIs from both functional and effect perspectives.

The rest of this paper is organized as follows. A literature review is presented in Section 2. Section 3 describes our proposed analytical framework for evaluating RI scientific effects. In Section 4, we select nine typical RIs in China, classify these RIs into three types, and comparatively analyze them using the analytical framework. A summary of four types of scientific effects and several policy suggestions are discussed in the fifth section to shed light on the governance of potential future RIs.

2. Literature review

With the increasing importance of RIs to economic and social development, the functions and outcomes of RIs are receiving greater attention from government organizations and academic researchers (e.g., Heidler and Hallonsten, 2015; Hallonsten, 2014; GSF, 2014). To better assess the effect of RIs, the chapter firstly reviews and offers a definition of RIs based on an analysis of extant definitions. Secondly, this paper reviews and compares several main perspectives on RI effects in the extant literature and discusses why scientific effects should receive more attention. Finally, we discuss the inadequacy of effect studies in the extant literature as the reason for our proposal of an analytical framework, and we then use this framework to explain the specific effects and their functions in the Chinese context.

Several organizations have proposed different definitions of RIs in the extant literature, as shown in Table 1. Clearly, different countries and organizations define RIs in different ways. This arises from the various contexts in which the term is used and the need to gain support from a full range of research endeavors. Among these definitions, those proposed by the US National Science Foundation (NSF, 2013) and the European Strategy Forum on Research Infrastructures (ESFRI, 2011) are popular in the extant literature. To facilitate the guidance and management of RIs, the Chinese State Council (CSC, 2013) has offered a definition of RIs that is related to development goals in China. Table 1 displays these three definitions. By comparing them, we find several common RI characteristics, including serving as a scientific tool, the influence of national infrastructure, and the systematic nature of RIs. Compared with normal scientific instruments, RIs feature intensive knowledge, capital, and engineering activities. For this reason, central governments are the primary funders of RIs and RIs exert more widespread influence than is typically expected of a scientific tool. Based on these considerations, this article defines RIs as large scientific instrumentation, facility, and equipment clusters that require large investments and complex engineering and networking efforts; receive funding primarily from national governments; and serve the science frontier, economic and social needs and national security. This definition is used to guide the construction of our analytical framework for evaluating the scientific effects of RIs.

There are several interesting studies about the evaluation of RI effects (see Table 2). Zuijdam et al. (2011) examined the roles and added value of RIs using the following four-type classification of effects: scientific effect, the creation of networks, economic value, and added value for society. The study investigated RIs in the Netherlands and analyzed the scientific effects in great detail. The OECD Global Science Forum (GSF, 2014) undertook a similar study of the impacts of the European Organization for Nuclear Research (CERN)—one of the most successful international RI organizations. Six impact categories were empirically defined as follows: scientific, input, training, national,

Table 2
Comparison among types of RI effects in the extant literature and descriptions of scientific effects.

Author	Types of RI Effects	Scientific Effect
Zuijdam et al. (2011)	Four aspect of added value: scientific effect, the creation of networks, economic value, added value for society.	Indispensable scientific tool, research scope and efficiency increase, multi-disciplinary research promotion, set target achievement in time, exponential increase in scientific output.
GSF (2014)	Six impact categories: purely scientific results; direct impact of RI spending; training effect; achieving national, regional and global goals; technological innovations and diffusion effect; education effect.	The most visible impact category; short-term impacts can range from spectacular to incremental; long-term impacts on science are, typically, difficult to forecast and to assess.
EC (2010)	Six impact categories: scientific, technological, economic, social, political, environmental.	Providing tools for frontier research, enhancement of research capacity, strengthening European Research Areas.
CAS (2007)	Six impact categories: scientific, national security and economic development, high-tech development, cultivating scientific talent, international cooperation, scientific competitiveness.	Providing extreme capability to solve contemporary fundamental science problems.