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Paths of technological capability building in complex capital goods: The case of hydro electricity generation systems in Iran

Mehdi Kiamehr *

Graduate School of Management and Economics, Sharif University of Technology, Tehran, Iran

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ABSTRACT

This paper investigates the accumulation of technological capability in latecomer suppliers of complex capital goods by exploring the issue in an Iranian supplier of large hydro electricity generation systems. The findings suggest that, contrary to the conventional paths of catch-up in Asian and Latin American mass-producing electronics firms, and instead of starting from early stages of product lifecycle, the technological capabilities in this case were acquired through a non-linear movement within the stages of designing and installing complex capital goods in projects: starting from the middle stage (engineering and realisation of complex goods in projects), moving to the last stage (operation and troubleshooting of complex goods), and eventually coming back to the first stage (conception and design of complex goods). A detailed analysis of learning mechanisms reveals that this path emerged largely due to the nature of "learning by projects" in this industry, engineering intensity of the tasks, and insufficiency of conventional knowledge transfer methods for building design capabilities in complex systems. The paper starts by developing an initial framework of technological capabilities that is then refined through this study and the resulting framework is presented as one of the contributions. Based on the findings, a set of new empirical categories of technological capabilities in complex capital goods is suggested to help future research in this area. Implications of this research are also discussed for global value chains literature. The conclusion touches upon the implications of the study for business strategy and policy.

1. Introduction

Within the innovation and catch-up literatures, a distinction has been made between mass-produced consumer goods, and low-volume, high-technology, high-value capital goods. The latter are sometimes known as complex capital goods. Chudnovsky et al. (1983, p.31-33) distinguish complex capital goods from simple (standard) capital goods based on technological complexity of the product (i.e. higher design intensity), nature and size of the demand (i.e. made in small quantities and according to customers' order vs. made in large numbers for an expected demand) and higher concentration in the supply market. This category of capital goods is also known as complex product systems (CoPS) in the innovation literature (Hobday, 1998; Acha et al., 2004). These goods underpin manufacturing, distribution and services in modern economies and play a central role in diffusion of modern technology throughout the economy (Rosenberg, 1982).

Telecommunication systems, aircrafts, locomotives, and power plant systems are examples of complex capital goods. These capital goods were originally developed in the advanced economies and developing economies have been main export markets for leading suppliers of these systems (Soderlund and Tell, 2009). A small amount of evidence suggests that some developing economies have gradually entered into production and export of these goods. In particular, in hydro and thermal electricity sector, companies such as IMPSA (in Argentina), Dongfang and Harbin (in China), Bharat Heavy Electrics Ltd. (in India), and Farab and Mapna (in Iran) gradually begun to carry out the designing, engineering and implementation of specific complex capital goods. According to the trade journals in these fields, the above companies are the only major suppliers from developing economies (see for instance International Journal of Hydropower and Dams, and Gas Turbine magazine).

However, there is little systematic empirical examination of these latecomer capabilities except for papers such as Lema and Lema (2012) and Hansen et al. (2014). Identifying the extent to which technological capabilities are built in latecomer contexts is an important theoretical and conceptual issue. While numerous studies have investigated it in the context of mass-manufacturing and electronics industries based on a fairly common framework developed by Bell and Pavitt (1995), the few studies that have looked into the catch-up in CoPS have focused largely on the learning mechanisms (see for example Hansen and Ockwell, 2014; Lema and Lema, 2012; Hansen et al., 2014), paying less attention to a systematic examination of the status

* Room 302, Graduate School of Management and Economics, Teymouri Blvd., Shahid Habibollahi St., Azadi Ave., Tehran, Iran.
E-mail address: kiamehr@sharif.edu.

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of technological capabilities. Lack of a common framework for empirical examination of technological capabilities makes connecting the findings of single studies, in order to form a coherent body, a challenging task.

Another important dimension of catch-up research is to investigate the paths through which technological capabilities have been accumulated in latecomer firms. While the existing literature for catch-up in consumer goods (see for example Kim, 1997; Hobday, 1995; Choung et al., 2014) suggests pathways for accumulation of technological capabilities, research in latecomer suppliers of complex capital goods has been again relatively quiet on this dimension (for exceptions see Hwang, 2000; Hansen et al., 2014; Teubal, 1984 and Chudnovsky et al., 1983). In the few studies that have addressed the paths, the lack of a common empirical definition of technological capabilities has caused researchers to use different vocabularies, making convergence among the findings difficult if not impossible. The well-recognised differences between complex capital goods and mass-produced goods (Davies and Hobday, 2005), including the extent of engineering and customisation involved in each delivery of complex capital goods and low volumes of production, suggest that existing patterns of building latecomer technological capabilities might need modifications in the case of complex capital goods.

The purpose of this paper is to provide an exploratory study of patterns of technological capability accumulation in latecomer suppliers of complex capital goods in one developing economy, namely Iran. The paper hopes to identify the paths of technological capability building in complex capital goods and explain the possible differences with the existing patterns in catch-up literature. The paper, therefore, aims to contribute to the extensive literature of catch-up at the firm level by extending our understanding of technological capabilities in complex capital goods. It also hopes to pave the way for emergence of an empirical definition of technological capabilities that can help organise existing and future empirical research in this area.

Iran is an interesting case for this study. Based on World Bank classifications, Iran was an upper middle income developing country in 2009. Iran has a fairly well-developed and integrated electricity network, providing access to the grid for more than 98% of its population, a figure well above the average of 73% in developing economies (IEA, 2010). As of January 2010, Iran had 56,817 MWs of installed electricity generation capacity, making it number 17 in the world and number one in the Middle East and West Asia in this respect. One intriguing aspect of the progress in Iran's electricity sector is the extent of its reliance on local capabilities. In addition to undertaking projects, Iranian companies appear to be involved in the engineering and manufacturing of complex systems such as turbines, generators and transformers. The official figures indicate that the export value of related services and equipment by local firms reached over US$ 3 billion in 2010 (Interview with the Deputy for Electricity, Ministry of Energy, on 2011/03/16).[1]

Among the different technologies of electricity generation, the Iranian firms seem to have developed stronger capabilities in the hydro power industry. Based on the official data from Iran's Ministry of Industry, Mine and Trade, Farab that is active in the design, engineering and build of hydro power plants has won the national award for best exporter three times, indicating that an internationally competitive capability has been developed in this firm although we need more systematic research to examine its strength. Despite a rather long history of development, only recently Iranian scholars have started systematic research on development of technological capabilities in Iran. The majority of the studies are at the national or policy level (see for instance Ghazinoory et al., 2009; Bagheri Mogaddama et al., 2011; Majidpour, 2012), and few studies that have looked at the electricity sector (for exceptions see Kiamehr et al., 2015) have not explored the hydro power industry and have not systematically investigated technological capabilities.

Section 2 looks at the global industry of design, engineering and installation of large hydro power plants from innovation and competition perspectives. Section 3 reviews the relevant literature. Section 4 presents the conceptual framework and discusses research design and methodology. Section 5 contains the evidence from the case study firm. Section 6 summarises the empirical findings and connects findings to the literature. Section 7 concludes the paper and discusses implications of this research.

2. The global industry of design, engineering and building large hydro power plants

A large hydro power plant is usually built along a dam. The water accumulated behind the dam is forced under control to enter the power plant at a specific flow in order to turn the turbine shaft. In this way, the energy that exists in the water and is enhanced through its flow from a higher altitude is absorbed by turbine blades and turned into mechanical work. The mechanical work is transferred to a generator that turns mechanical energy, in the form of a rotating shaft, into electricity. This rather simple concept of a hydro power plant is complicated in implementation. The large hydro power plant is normally composed of four sections: a turbine intake system that includes valves to control the flow of water into the power plant, a spiral case to increase water energy by rotating it around, and a wicket gate system to control the water flow that touches the turbine at the end of spiral case. The turbine itself is composed of blades that are specifically and carefully designed in each plant to convert the water energy into mechanical work at the highest efficiency. The water then is directed to the back of the plant through a draft tube. Usually the electricity generator is located above the turbine and its output is sent to a transformer in order to become suitable for transmitting over the networks of electricity. The turbine intake system, its blades, and its control systems are the most complicated technological components of hydro power plant. In addition to the above systems, which are called core-equipment in practice, there are a variety of other systems in a large hydro power plant that prepare the conditions for an effective use of core-equipment. These systems include HVAC system to provide pressurized air and ventilation for components and for operating rooms, fire-fighting systems to protect expensive components, internal power and electricity system for the plant facilities, cranes and machineries for maintenance and transportation. These systems are called non-core equipment or non-core systems.

To discuss the nature of technological capabilities in power generation projects, this section elaborates the set of tasks in a typical hydro plant project. Fig. 1 illustrates these activities. This work is largely based on the practice and experience in Iran, which have developed over time through cooperation with international consultants and leading suppliers. Furthermore, the literature on the industry with regard to other countries (Charoenngam and Yeh, 1999; Ling and Lau, 2002) and information gathered from websites of leading firms have been extensively consulted to investigate the differences. It is therefore expected that this description would be broadly valid in the global context.

During the conceptual design phase, the key characteristics of the plant are specified in terms of the optimum number of power units, the capacity of each unit and the overall technological specification of the power systems. This phase is often carried out by engineering consulting firms. The initial designs, however, might change during the later stages. The initial designs are then transferred to prime contractors or EPC contractors which are often large firms and most often leading firms from advanced economies. These leading firms, as examined later in this section, have exclusive knowledge of designing advanced core equipment and possess a long experience in the field, capable of attracting the client's trust. The second phase normally starts with the design and engineering of core equipment. As every large hydro power site has its own profile of water flow rate and head, the

[1] http://news.moe.org.ir/vdcg3x9x.ak93q4prra.html (in Farsi).