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Micro-level technological capability accumulation in developing economies: Insights from the Brazilian sugarcane ethanol industry

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A B S T R A C T

Accumulation of indigenous innovative capabilities in firms in developing economies ('latecomer firms') may contribute to sustainable industrial development. To enhance understanding of capability accumulation processes in latecomer firms, this study examines inter- and intra-firm variations in the levels and time scales of micro-level capability accumulation, related interdependencies with external organisations, and implications for innovation. Drawing on an empirically grounded study of firms from the Brazilian sugarcane ethanol industry, this study finds that the implementation of ambitious and wide-ranging innovations depends on varied internal and external capabilities. However, there are considerable variations between and within firms in their internal and external capability accumulation for specific technological functions. Firms with greater capabilities and openness undertake more ambitions innovations. Using a nuanced micro-level approach that goes beyond the firm as the main unit of observation, this study furthers understanding of the intricate, dynamic, and interdependent processes of latecomer firms' capability accumulation. It also allows deeper analysis of the implications of firms' innovative capability building for sustainable industrial development in developing economies.

1. Introduction

The orientation of innovation towards cleaner technologies and production systems that reduce both costs and environmental damage is of interest to research into technological capability building in developing economies (Ely and Bell, 2009). These concerns arise from the potential environmental damage derived from economic and industrial growth in low- and middle-income countries. It has been argued that mitigation of this environmental burden of growth depends largely on the accumulation of indigenous capabilities for innovative activities within firms in developing economies – 'latecomer firms' (Bell, 2009, 2012). Indeed, the accumulation of innovative capabilities in latecomer firms is intrinsically linked to sustainable industrial development (Berkhout, 2012; Ockwell and Mallet, 2012). Industrial development that encourages innovative capability accumulation for environmentally friendly technologies may produce production modes beyond the fossil-fuel industrial mode (Lee et al., 2014).

Over the past four decades, many studies have emerged that investigate firm-level capability building in developing economies and industries (see reviews by Figueiredo, 2001; Bell, 2006; Bell and Figueiredo, 2012), including clean technology industries (Marigo et al., 2010; Lewis, 2011). However, some issues remain poorly explored. For instance, heterogeneity of capability accumulation processes is expected between and within firms (Bell and Pavitt, 1995; Figueiredo, 2001), but this issue has received little empirical treatment. Although studies have examined inter-firm differences in *current* technological capabilities (Hansen and Ockwell, 2014; Lema et al., 2015b), less attention has been paid to differences between and within firms in the *processes* by which they accumulate diverse levels and types of technological capabilities, especially regarding renewable energy industries. Additionally, few studies exist that explicitly tackle the time scales involved in the capability-building process (Figueiredo, 2001; Ariffin, 2010).

In contrast, considerable studies exist that assume that industrial innovative capabilities of developing economies are associated with breakthrough innovations from research institutions (United Nations Framework Convention on Climate Change – UNFCCC, 2009; Raven and Geels, 2010; World Bank, 2010). Such studies assess innovative capabilities via cross-sectional studies using standard proxies such as research and development (R&D)

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indicators and patents (Walz and Marscheider-Weidemann, 2011; Wu and Mathews, 2012). However, these proxies cannot completely capture a firm's innovative capability, particularly for firms with capabilities other than R&D (Bell and Pavitt, 1995; Bell, 2012). Nevertheless, judgements about 'dynamics' are made, generally indicating the absence of change or false negative conclusions (Ariffin, 2010).

Standard proxies also neglect some capabilities required for diverse innovative activities (Patel and Pavitt, 1994; Bell, 2009). For example, Rock et al. (2009) demonstrated the importance of engineering-based, incremental innovations for sustainable technological development for firms in Malaysia; Huenteler et al. (2014) demonstrated the importance of local and engineering-based technological capabilities for renewable electricity cost reduction in Thailand. Therefore, considering that firms' technological capability-building processes change slowly, short-term observations, 'snap-shots' or statistical indicators cannot encompass the movement and time scales involved (Bell, 2006).

Additionally, technological capability-building and innovation processes that occurred in individual and vertically integrated latecomer firms are shifting towards organisationally decomposed arrangements (Schmitz and Strambach, 2009) and have become decentralised (Lema et al., 2015a). Such phenomena reflect the interdependent nature of innovation in advanced economies (Chesbrough, 2003; Laursen and Salter, 2006), including the role of inter-organisational R&D cooperation to enhance environmental innovations (Rodriguez and Wiengarten, 2017).

Research into latecomer firms has addressed this issue through approaches such as the 'technology linkage capability' (Arnold and Thuriaux, 1997) and 'linkage, leverage, and learning' (Mathews, 2006) approaches. Building on these, Scott-Kemmis and Chitravas (2007) identified inter-firm heterogeneity in innovation strategies in Thailand, connecting with partners to exploit external knowledge. However, they did not link these strategies with micro-level capability-building paths. Some studies considered the importance of other organisations in firms' innovative activities (Dantas and Bell, 2011; Chuang and Hobday, 2013). However, most literature concerning latecomer firms has focused on capability accumulation *within* individual firms rather than on inter-organisational dimensions (Bell and Figueiredo, 2012).

Therefore, studies are lacking that examine the inter- and intra-firm heterogeneity in latecomer firms' technological capability-accumulation processes and the link to firms' external engagement strategies to enhance their capabilities and innovative activities. This study explores this research gap by asking how firms differ in their technological capability-accumulation paths and time scales, and in their interactions with external organisations in implementing innovative activities.

To address this research question, this study adopts a micro-level approach, going beyond the firm as the main observation unit, to investigate the capability accumulation for *specific technological functions within* firms. It adopts a comprehensive and empirically grounded approach that captures the levels and time scales of the capability-building process and links them with the firms' external technology sourcing strategies and implications for innovative activities. This study therefore improves understanding of latecomer firms' technological capability building and the contribution to environmentally friendly industrial development.

The study examines the Brazilian sugarcane ethanol industry, the world's largest sugarcane ethanol producer (Brazilian Sugarcane Industry Association – UNICA, 2016). Brazil is the world's seventh largest greenhouse gas (GHG) emitter and one of five countries with the greatest potential to reduce emissions by 2030, playing a significant role in global climate change with implications for both research and policy actions (World Resources Institute – WRI, 2015). Although the Brazilian sugarcane ethanol industry has been studied from various standpoints, such as innovation systems (Dantas, 2011; Furtado et al., 2011; Andersen, 2015) and industrial policies (Mingo and Khanna, 2014), micro-level technological capability-building studies are scarce. This paper is organised as follows: Section 2 outlines some features of the Brazilian sugarcane ethanol industry. Section 3 presents the study's conceptual background, followed by the methods in Section 4. The findings are presented in Section 5 and discussed in Section 6, followed by the conclusion, limitations, and future research suggestions in Section 7.

2. The Brazilian sugarcane ethanol industry: a brief overview

Sugarcane ethanol is a type of biofuel. There are three biofuel generations: (i) the 'first generation' uses feedstocks, such as sugar or starch (e.g. sugar cane, maize) to produce ethanol, and oilseed or waste oil to produce biodiesel (these are currently the only commercially available large-scale biofuels); (ii) the 'second generation' uses non-food feedstock (so-called lignocellulosic biomass, such as crops residues) to obtain diesel, jet fuel, and gasoline that can be used without blending in existing vehicles (i.e. a 'drop-in' replacement for fossil fuels); (iii) the 'third generation' is not yet cost-effective and involves production of diesel and jet fuel from feedstocks such as microalgae. Because of their technical complexities, the second and third generation biofuels involve intense R&D efforts (International Renewable Energy Agency – IRENA, 2016).

Sugarcane ethanol is a biofuel produced from the fermentation of sugarcane juice and molasses. Ethanol can be (i) blended with gasoline at levels ranging from 5 to 27%, reducing petroleum use, or (ii) used as pure ethanol (85–100% ethanol) for powering specific engines. Sugarcane ethanol helps prevent engine knocking and generates more power in higher compression engines. It has become a leading renewable fuel for transport, as it is a clean, affordable, and low-carbon biofuel. It also contributes to climate change mitigation: (i) it adds oxygen to gasoline, reducing air pollution and harmful tailpipe emissions; (ii) it reduces GHG emissions more than any other liquid biofuel commercially produced today, by cutting CO_2 emissions by 90% on average (Goldenberg, 2007; IRENA, 2016). Additionally, every litre of petrol replaced with sugarcane ethanol reduces emissions by 90%. The by-products of sugarcane ethanol production (bagasse and straw) can be sources for bioelectricity cogeneration. In 2014, sugarcane mills met approximately 4% of Brazil's electricity demand (UNICA, 2016).

Nevertheless, biofuels such as sugarcane ethanol have been criticised for potential GHG emissions and competition with food crops (Pereira and Ortega, 2010) [1]. In this industry, the harvesting of sugarcane through burning and the storage and transportation of residues can produce GHG emissions. Some approaches can mitigate these effects, e.g. sugarcane harvesting without burning, using renewable fuels instead of fossil fuel and optimising the transportation of products and inputs (Ometto and Roma, 2010).

Regarding sugarcane burning in Brazil, Federal Decree 2661 of 1998 established a gradual elimination of sugarcane burning over a 20-year period. The state of São Paulo, southeast Brazil, responsible for the majority of Brazil's ethanol production, enacted the Agro-environmental Protocol in 2002, which established progressive elimination of burning from 2007 to 2014. Such measures increase the availability of straw as a biomass source for cellulosic ethanol production. Additionally, harvesting mechanisation maintains organic material concentrations in the soil, increasing CO_2

[1] I thank a reviewer for raising this point.