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Additive manufacturing and the global factory: Disruptive technologies and the location of international business[☆]

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ABSTRACT

Additive manufacturing (AM) is an emergent technology that is shifting the nature of production, sourcing, and other value-chain activities. AM has the potential to substantially disrupt the structure and operations of international business. In this paper, we leverage the global factory concept (e.g., Buckley & Ghauri, 2004) to frame our discussion of the likely impact of AM on global production. We identify and conceptualize specific variables and relationships to offer a nuanced explanation that highlights the potential re-distribution of global production at four levels of analysis – global, country, local area, and household. We propose how key variables – Intellectual Property Status, Industrial Standards, Branding, Aesthetics, Authenticity, Material Type, Complexity, Customization, Size, Logistical Complexity, Delivery Timeliness, Demand, Access, and Technical Competence – likely will impact localization of production. We examine industries and production activities likely to be most affected by AM. We conclude with a discussion of managerial and practical implications and identify avenues for further research.

1. Introduction

Additive manufacturing (AM) is emerging as a potentially disruptive technology (Lipson & Kurman, 2013; Rayna & Striukova, 2014). Numerous scholars suggest that the emergence of AM on a wide scale likely will affect the pattern of global production and potentially introduce an era of mass customization (Anderson, 2012; Berman, 2012; Campbell, Williams, Ivanova, & Garrett, 2011; D'Aveni, 2013). In the wake of AM's rise, global production gradually will become more localized (Ben-Ner & Siemsen, 2017; Laplume, Petersen, & Pearce, 2016). Managers likely will need to re-evaluate established models of international manufacturing and revise current approaches to global production strategy (D'Aveni, 2013).

AM technology is the collective term for technologies that enable “3D printing” of physical objects. Until recently, AM has been employed mainly for prototyping or by young firms operating in niche markets (Müller, Karevska, Wienken, & Kilger, 2016; Strange & Zucchella, 2017). However, with an increasing number of materials that AM technologies can handle – including high strength alloys such as Inconel – applications of the technology are becoming increasingly relevant in numerous industries. Hence, AM is currently applied in the aircraft industry for low-volume parts production (Gambell et al., 2017), the medical industry to customize prosthetics, and in dentistry to create high precision dental implants (Müller et al., 2016). AM likely will help reduce the capital needed for international start-ups and substantially transform business models in established multinational enterprises (MNEs) (Campbell et al., 2011; D'Aveni, 2013; Fenn, 2010; Lipson & Kurman, 2013; Wittbrodt et al., 2013). The full potential of AM technology likely rests in coupling it with other constituent technologies in industry 4.0 (Strange & Zucchella, 2017), such as web 2.0 applications (Gao et al., 2015). Industry 4.0 refers to the current trend of automation and data exchange in manufacturing technologies. Web 2.0 reflects the emergence of web pages that feature dynamic or user-generated content and links to social media. ICT companies or “IBusiness” firms (Brouthers, Geisser, & Rothlauf, 2016) offer digital platforms that allow users to interact with each other and the producer to generate joint value through co-creation (Prahalad & Ramaswamy, 2004b). Customers are allowed access to a platform in which they can consume, use, add, and remix data. This creates an ‘architecture of participation’ (O'Reilly, 2007) in which users co-create content in a thematic community (Prahalad & Ramaswamy, 2004a). AM and AM combined with web 2.0 technology likely will have a disruptive impact on global markets, industrial ecosystems and firms for years to come (Anderson, 2012; D'Aveni, 2013; Petrick & Simpson, 2013; Rayna & Striukova, 2014).

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Currently, however, we have yet to witness large-scale adoption across industries (Strange & Zucchella, 2017), although some scholars believe such adoption would provide substantial economic advantages, or additional advantages, in industries such as aerospace and defense, automotive, medical and consumer goods (Gambell et al., 2017; Müller et al., 2016).

This disruptive potential already has been examined in numerous news stories, case studies, and books (Anderson, 2012; Fitzgerald, 2013; Hornick 2015; see Lipson & Kurman, 2013). Nevertheless, there has been little research on the impact of AM technologies on international business. Extant scholarly literature emphasizes the technical aspects of AM (see Amon, Beuth, Weiss, Merz, & Prinz, 1998; Bak, 2003; Gao et al., 2015; Rengier et al., 2010; Wu, Thames, Rosen, & Schaefer, 2013; Zhai, Lados, & LaGoy, 2014), potential applications in the natural sciences (see Gross, Erkal, Lockwood, Chen, & Spence, 2014; Symes et al., 2012), special applications in health care (Gelinsky, 2016; Goldstein, Smith, Zeltsman, Grande, & Smith, 2015), and even speculations on how the technology can be applied in manufacturing a future lunar outpost (Cesaretti, Dini, De Kestelier, Colla, & Pambaguian, 2014). However, the potential impact of AM on MNE processes and operations such as marketing, management, logistics, and supply chains has been the subject of only minimal research (see Campbell et al., 2011; D'Aveni, 2013; Laplume, Petersen, & Pearce, 2016). For example, Strange and Zucchella (2017) investigated AM in relation to constituent industry 4.0 technologies, including big data analytics, agile robotics systems, and the Internet of things. They find that taken together these technologies may herald a new era and but also may expose original manufactures to hacks of existing products (Strange & Zucchella, 2017). Accordingly, intellectual property status will tend to have some influence on the location of production (Desai & Magliocca, 2013). Laplume et al. (2016) suggest that AM affects the MNE's role in coordinating global value chains and could give rise to household-level production. They theorize that several factors – including type of material, customization, delivery speed, and low cost – likely will influence AM's potential industry effects (Laplume et al., 2016).

Despite much exuberance about the future of AM (Holweg, 2015), however, systematic and scholarly research is needed to investigate the technology's potential impact in international business. This paper seeks to address this gap. Research is needed to investigate AM's potential impact on the locational dimensions of internationalization, which have been highlighted as an important avenue of research (Buckley, 2009b).

In this paper, we use the term 'localization of production' to refer to manufacturing at a place at, or near, the point of end-user consumption. We leverage the global factory perspective (e.g. Buckley & Ghauri, 2004) to develop a conceptual explanation of the impact of AM relative to models and frameworks in international business. We aim to stimulate a more conceptual, grounded discussion of the impact of AM. To this end we identify and suggest the likely effect of numerous variables on the localization of production, and offer propositions to support future research.

This paper will proceed as follows. We introduce AM technology and embed it in traditional internationalization perspectives as well as the global factory (Buckley, 2009b; Buckley & Ghauri, 2004; Eriksson, Nummela, & Saarenketo, 2014). We leverage the global factory framework to guide discussion of the potential adaption of AM in international business. We then develop a conceptual model that describes various AM-related independent variables and their likely impact on localization of production. Based on these variables, we advance propositions that can guide further research and conclude with managerial implications of AM's likely effects in international business.

1.1. The impact of digitalization of goods in international business

Major technological innovations occasionally arise that engender a decisive cost or quality advantage and that may affect entire industries, disrupting or even overturning an existing product or production paradigm (e.g., Anderson & Tushman, 1990). For example, word-processing computers superseded typewriters; smartphones disrupted the laptop computer industry; and LED technology has disrupted, and likely will replace, conventional incandescent lighting technology. AM technology has the potential to affect many industries simultaneously. This helps explain why predicting the long-term impact of 3D printing is relatively complex.

In conventional economics, a 'technology shock' is the emergence of a new technology that substantially increases production of some output (Schilling, 2015; Shea, 1999). Ordinarily, a technology shock is thought to significantly increase output, given the same level of input, often labor. More broadly, a technology shock usually is thought to benefit some type of economic activity and may substantially impact production, often in the form of manufacturing plants (Landes, 2003; Schilling, 2015; Shea, 1999). For example, the widespread introduction of electricity represented a positive technology shock because it dramatically increased the efficiency with which goods could be manufactured. The impact of a technology shock also could have a negative effect on an existing production paradigm, and might engender a reduction in output for a given set of inputs. In conventional economics, however, negative shocks are relatively rare (Landes, 2003; Schilling, 2015; Shea, 1999).

A technology shock is similar to a "disruptive innovation," an invention or technological improvement that creates a new market and value network, and eventually disrupts an existing market and value network, and disrupts established markets and the firms most active in those markets (e.g., Bower & Christensen, 1995; Christensen, 1997). Disruptive technologies create industrial growth by penetrating and/or creating "new industries through the introduction of products and services that are dramatically cheaper, better, and more convenient" (Kostoff, Boylan, & Simons, 2004, p. 141). A sufficiently groundbreaking innovation can disrupt the entire ecosystem associated with an existing market structure (Bower & Christensen, 1995; Christensen, 1997).

Entrepreneurs and start-up firms are often at the forefront of disruptive innovations because they have relatively little invested in the existing production paradigm. Disruptive innovations may take considerable time to become mainstream, partly because the existing ecosystem resists change, especially change that threatens the current structure (Assink, 2006; Bower & Christensen, 1995; Christensen, 1997). Large, older, incumbent firms tend to ignore disruptive innovations in early stages because, initially at least, market prospects from the innovations seem limited and too small to provide substantial returns (Bower & Christensen, 1995; Christensen, 1997). By contrast, entrepreneurs and start-up firms may have relatively little invested in the existing paradigm and are more given to adopting a new paradigm, particularly if it shows much promise in increasing the efficiency or effectiveness of production, or in providing one or more competitive advantages (Christensen, 2003). Technology evolves, and in the process of creating some major new innovation, some older, less effective technology usually fades away (Gassmann, 2006). New technologies gain momentum and impact the existing production paradigm when they are seen to provide substantial, major benefits to a critical mass of interested parties.

The aggregate effect of AM technology might be to increase the efficiency or effectiveness of goods production. Efficiency and effectiveness could arise by placing the good more efficiently and in a more customized or desirable form, into the hands of individual buyers, using a more efficient supply chain of design, raw materials, and final production. We anticipate that widespread dissemination of AM technology will tend to disrupt the current global factory paradigm and existing production ecosystem, with attendant effects on the nature of work and the labor force in many industries.

Experts have compared the potential impact of AM technologies to the radical changes triggered by the rise of information and