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Building the layers of a new manufacturing taxonomy: How 3D printing is creating a new landscape of production eco-systems and competitive dynamics

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ABSTRACT

Recent innovations in 3D printing technologies and processes have influenced how products are designed, built and delivered. However, there is a significant gap in our knowledge of how 3D printing is impacting on manufacturing eco-systems within different industries and contexts. Drawing inspiration from earlier manufacturing taxonomies as well as the competitive dynamics literature which provides insights into industries' moves from straightforwardly rivalrous frameworks, through competitive-cooperative exemplars, into the more recent relational-based competition. Basing our analysis on a systematic review of organisations' use of 3D printing, we develop a new taxonomy explaining the many areas the technology can impact. In addition to offering a comprehensive framework to conceptualise the impact of 3D printing, we emphasise the role of users in co-creation and personalisation. While 3D printing has been touted as disruptive, we suggest that our new taxonomy offers a richer understanding of the ways firms can operate in a 3D printing context. We furthermore apply the relational competition category of the competitive dynamics model to our taxonomy, showing how 3D printing influences the modes and aims of competition, roster of actors and action toolkits within the different industry sectors.

1. Introduction

Rapidly increasing developments in automation technologies, including 3D printing, have changed how products are designed, built and delivered. However, there is still not a clear-cut answer about the impact of this new wave of technological progress on existing market structures. In this paper we address the significant gap in knowledge of how 3D (three-dimensional)[1] printing is impacting manufacturing eco-systems. Drawing inspiration from earlier taxonomies of sectoral patterns of innovation (e.g. Castellacci, 2008; Miozzo and Soete, 2001; Pavitt, 1984), we offer a framework for plotting and comparing the impact of 3D printing. Basing our analysis on case studies of more than 20 firms we construct a taxonomy to accommodate developments in 3D printing and show how these are changing the rules of the game and competitive dynamics in different industry sectors. In so doing we are contributing to the advances made in the literature on competitive dynamics where the move from rivalrous frameworks through competitive-cooperative dynamics, to relative competition (Chen and Miller, 2012, 2015; Ghemawat and Cassiman, 2007) is clearly evident in the cases we present. We also emphasise the role of users in co-creation and personalisation and how this varies according to the level of use of 3D printing at different stages between end products and various types of manufacturing strategies.

3D printing refers to "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" (Standard, 2012). Originally 3D printing was mainly used for prototyping (Rayna and Striukova, 2016). As the technology improved, 3D printers have found wider application, including making tools used for traditional manufacturing and the production of end-products (Royal Academy of Engineering, 2014). It provides companies with a wide range of both benefits and challenges. Firms that employ 3D printing are able to increase supply chain

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[1] We know that there are discussions both in the literature and in industry about the differences between additive manufacturing and 3D printing. For the sake of coherence and brevity in this paper we use the term 3D printing to encompass both types, except where it is important to make a distinction between the two.

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efficiencies, reduce time to market, move from mass production to mass customization, and sustain the environment (Ford, 2014). But it is also bringing radical change to manufacturing systems and challenges companies to reinvent their business models.

Bogers et al. (2016) argue that 3D printing is changing, and in some cases radically disrupting, power structures and supply chain dynamics. This forces firms to change and enables the startup of new firms. However, understanding these changes is a rather complicated matter (Rayna and Striukova, 2016). Limits to the size of goods produced by 3D printing, difficulties in achieving mass production, issues with materials, and certification standards, constrain adoption in some industries, but not others (United States Government Accountability Office, 2015). While this technology is evolving and has the potential to transform manufacturing ecosystems, a granular understanding of the socioeconomic consequences of 3D printing lags activity (Ford et al., 2016). Empirical investigations of how different industries have transitioned to, or employed, 3D printing technologies are sparse. This paper undertakes a detailed review of the application of 3D printing technologies in different manufacturing industries in order to understand the impact of 3D printing on business ecosystems and the implications for firms and customers. As such we adopted an illuminative research strategy in which we sought exemplar organisations within different types of industries in order to understand the changes that 3D printing has brought to their operations.

The advent of 3D printing has been seen in many different ways, such as an example of a disruptive innovation (Christensen, 1997; Christensen and Raynor, 2003; Rayna and Striukova, 2016), or as an accelerated move towards the digitisation of manufacturing. Its impact has been substantial, leading to radical and even Schumpeterian changes in some industries and the manufacturing landscape (Manyika et al., 2013; Petrick and Simpson, 2013; Rayna et al., 2015; Rayna and Striukova, 2016; Schumpeter, 1939). Technological transitions such as this influence existing industries, encourage the development and expansion of new industries, and can even overthrow existing industries (Sandström, 2011; Schmidt and Druehl, 2008). Many questions remain pertaining to the fundamental impact of 3D printing and also more specifically on individual firms and industries. The technology is also a pertinent example of the competitive dynamics literature at play as we see industries moving away from the language of combat to examples reflecting the “action/reaction dyads, streams of actions and relative interdependence” described in the literature (Chen and Miller, 2012, 2015).

In addition, because of the role of digitisation, 3D printing has also been significant in newer business models and emerging industries. It has been grouped with other disrupted technologies such as digital books and music (Berman, 2012). However, there are some differences, mainly to do with the physical nature of the product: “While movies and music are nowadays predominantly transferred over the Internet to be ‘manufactured’ at home, it is unlikely that all manufacturing will follow this path, with every single object being fabricated at home on a personal 3D printer” (Rayna and Striukova, 2016, pp. 214–215). However, 3D printing could be used to manufacture some low volume customized products when economically attractive (Berman, 2012; Petrick and Simpson, 2013; Petrovic et al., 2011), accelerating a cultural shift towards do-it-yourself inventing and making (Anderson, 2012).

Some believe that a 3D printer will someday be in every home, making the industrial giants of the past redundant (Anderson, 2012). Easy access to materials, machines and digital software allows individuals to design and manufacture their own creations. These factors also provide significant opportunities for co-creation based around Web 2.0 technologies (Rayna and Striukova, 2015). A number of new online platforms now enable businesses, designers and individuals to crowdsource the design or manufacturing of their products. Such emerging user communities provide many opportunities to consumers, and considerable competitive challenges to existing producers (De Jong and de Bruijn, 2013). As these technologies improve, they can potentially alter the structure of competition. Industry borders could be transcended and value chains disaggregated, creating new competitive dynamics (Rayna and Striukova, 2016).

3D printing technologies have the potential to enable the digitalisation and democratisation of manufacturing. Thus earlier taxonomies of industries do not take into account some of the important changes 3D printing enables such as consumer involvement and competitive interactions across various industries, confronting firms and individuals with new opportunities and challenges. 3D printing technologies have enabled the personalization of products tailored to the individual needs of consumers and has accelerated the trend towards co-creation in some industries (Rayna and Striukova, 2016). Rivalrous behaviour is not limited to similar firms within the same industry but brings together competitors from different industries (Chen and Miller, 2015).

There has been limited attempt to understand how the evolution of 3D printing impacts firm's behaviour and contributes to the development of a new taxonomy of manufacturing industries. We extend research on previous industrial taxonomies in several ways. First, we offer an updated taxonomy based on the changes that 3D printing has enabled. We believe that an updated categorization of industries and firms based on new dimensions, including the location of production in the supply chain and consumer involvement in the development of the product and competitive dynamics, is necessary. Second, we synthesise the literature of co-creation and personalisation with technological content of earlier industry taxonomies, to understand the role of the user and supply chain firms in production. Third, we draw on the competitive dynamics literature and recognise that competitive dynamics do not only exist between homogeneous firms, and the dyadic relationship between a focal firm and its main rival is no longer sufficient for explaining a firm's competitive behaviour (Chen and Miller, 2015). Firms from previously adjacent industries are crossing industry borders and shifting position in the supply chain to compete with previously unlikely rivals. Finally, we suggest that the new taxonomy will point out the main implications of this theoretical view for individuals and firms who are considering adopting 3D printing technologies and technology manufacturers who want to know the next niche market for their products (Table 1).

Through the analysis of secondary data sources on the top industrial users of 3D printing and drawing inspiration from earlier typologies, we develop a new, extended and updated, taxonomy of industry types that facilitates an understanding of how 3D printing has changed the rules of the game and competitive dynamics in different industries, both modern and traditional (Bogers et al., 2016; Jia et al., 2016). The new taxonomy is applied in order to develop an understanding of the diversity of sectors and map the differences between them (Archibugi, 2001).

As such, this article addresses three questions about the impact of 3D printing. First, how is 3D printing being applied in different industries? Second, what changes are happening in existing market and supply structures, and what are the implications for firms and their

Table 1
Leading implementers of 3D printing technologies (Source: Wohlers, 2017 adapted by the authors).

Industry	Relative % use of 3D printing
Industrial/Business machines	19%
Aerospace	18%
Motor vehicles	15%
Consumer products/Electronics	13%
Medical/Dental	11%
Academic Institutions	8%
Other	7%
Government/Military	6%
Architectural	3%
Total	100%