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AMT adoption and innovation: An investigation of dynamic and complementary effects

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ABSTRACT

The ability to innovate successfully is a key corporate capability, depending strongly on firms' access to knowledge capital: proprietary, tacit and embodied. Here, we focus on one specific source of knowledge – advanced manufacturing technologies or AMTs – and consider its impact on firms' innovation success. AMTs relate to a series of process innovations which enable firms to take advantage of numerical and digital technologies to optimise elements of a manufacturing process. Using panel data for Irish manufacturing plants we identify lengthy learning-by-using effects in terms of firms' ability to derive innovation benefits from AMT adoption. Disruption effects are evident in the short-term while positive innovation benefits occur six-plus years after adoption. Strong complementarities between simultaneously adopted AMTs suggest the value of disruptive rather than incremental AMT implementation strategies.

1. Introduction

Our objective in this paper is to understand the AMT-innovation relationship, specifically focusing on the temporal profile and complementary effects of AMTs on innovation performance. The ability to innovate successfully is a key corporate capability, depending strongly on firms' access to knowledge capital: proprietary, tacit and embodied (Al-Laham et al., 2011; Wu and Shanley, 2009; Tzabbar et al., 2008; Kyriakopoulos and de Ruyter, 2004). The relationship between proprietary knowledge (e.g. patents) and innovation has been widely explored (Artz et al., 2010; Mansfield, 1986), as has the relationship between innovation and tacit or un-codified knowledge (e.g. workforce skills) (Comacchio et al., 2012; Doran and Ryan, 2014; Knockaert et al., 2009; Ichijo and Kohlbacher, 2008). External knowledge sharing positively impacts innovation performance, as do strong networks (Bellamy et al., 2014; Love et al., 2011; Ritala et al., 2015). Less attention has been paid to the impact on innovation of the knowledge embodied in firms' capital equipment. Here, we focus on one specific source of embodied knowledge – advanced manufacturing technologies or AMTs – and consider its impact on firms' innovation success. AMTs relate to a series of process innovations which enable firms to take advantage of numerical and digital technologies to optimise elements of a manufacturing process. These may relate to the control of individual pieces of production equipment – as in numerically controlled, computer numerically controlled (CNC) machinery or robotics – the automated movement of items during the manufacturing process – as in automated materials handling (AMH) – or the integration and optimisation of the production process – as in computer aided production management or computer integrated manufacturing (CIM) (Zammuto and O'Connor, 1992).

Previous studies have considered the factors which shape firms' adoption of AMTs, suggesting positive links between AMT adoption and firm size, skill levels and more flexible organisational cultures (Zammuto and O'Connor, 1992). More recently, Gomez and Vargas (2012) illustrate, with a sample of Spanish manufacturing firms, that R&D investments increase the likelihood of AMT use. Export intensity and being part of a business group are also positively associated with technology use (Gómez and Vargas, 2012). A limited number of studies have also attempted to quantify the impact of AMT use on employment and productivity. Bartelsman et al. (1998), for example, report higher average growth rates of total factor productivity and employment for Dutch firms which employed AMT. Employment growth has also been linked to AMT

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use in France, the UK and the US, while employment reductions have been noted in Italy, Norway and Denmark (Bartelsman et al., 1998). Arvantis and Hollenstein (2001), in their study of AMT adoption in Switzerland, highlight the need for further analysis of the relationship between technology diffusion and economic growth. In terms of the relationship between AMTs and innovation, research is limited. However, Barge-Gil et al. (2011) consider the impact on innovation where a firm uses forms of computerized aided manufacturing (CAM), robotics or CAD/CAM. In their data for Spain, adoption of AMTs is strongly correlated with firm size but only weakly correlated with other firm characteristics such as R&D intensity or design. AMT adoption then has a positive and significant effect on the probability of product innovation only for non-R&D performers but a positive impact on probability of process innovation for both R&D performers and non-performers. Nair et al. (2013) report that exporters engage in more skilled use of manufacturing technologies than non-exporters, resulting in less rejects and shorter lead times. In addition, Khanchanapong et al. (2014) report complementary benefits of AMT and lean practices use on a range of operational performance dimensions, including quality, lead-time, flexibility and cost.

Other studies report the influence of AMT in the innovative process for low-and-medium technology firms (Santamaría et al., 2009) and for small firms (Raymond et al., 2009). Both studies suggest the potential value of considering in more detail the factors which may condition the effects of AMTs on innovation. Other studies have also suggested the difficulties which firms face in the effective implementation of AMTs, creating the potential for disruption effects, learning-by-using effects and time-lags in the effect of AMTs on innovation (Tyre and Hauptman, 1992). Chan et al. (2015) report that the barriers to successful AMT implementation are experienced more acutely by smaller companies, with the lack of appropriate or proper training being the most severe barrier.

Using panel data for Irish manufacturing firms, which provides AMT adoption histories, we focus here on the relationship between innovation and the prior adoption of AMTs. Specifically, we ask whether, and over what period, the adoption of AMTs impacts on firms' innovation success. The AMTs examined include computer-aided manufacturing (CAM), automated materials handling (AMH), computer-integrated manufacturing (CIM) and robotics. Most, if not all, of the prior studies of the relationship between AMTs and innovation have been based on cross-sectional data making causality difficult to identify, and providing little information on the nature of the learning effects and lags involved in AMT adoption and the potential benefits for innovation. Our study makes three main contributions. First, it clearly highlights the temporal profile of the performance benefits of individual AMTs, highlighting short-term disruption effects but longer-term benefits. Second, it highlights complementarities between the adoption of specific AMTs, and third it suggests the role of learning-by-using effects in the shaping of the AMT–innovation relationship (Rosenberg, 1982).

The rest of the paper is organised as follows. Section 2 provides a brief overview of AMTs, and their degree of integration in the manufacturing process; a discussion of the relationship between innovation and AMTs; and, the role of complementarities learning-by-using effects in the enhancement of firms' innovation performance. Section 2 also outlines our three hypotheses relating to the potential impacts of prior AMT adoption on innovation. Section 3 describes the data used in our study. Our empirical analysis is based on a panel dataset relating to Irish manufacturing firms which were surveyed at regular intervals over the 1994–2008 period. Section 4 outlines the main empirical results and Section 5 discusses the implications of this work. Variable definitions are included in an Annex A.

2. Concepts and hypotheses

2.1. AMTs and Innovation

AMTs relate to a series of process innovations which enable firms to take advantage of numerical and digital technologies to optimise elements of a manufacturing process. We briefly describe the four AMTs studied in this paper and subsequently categorise them based on the extent to which they integrate elements of the manufacturing process.

Computer-aided manufacturing (CAM) is the use of computer software to control machine tools and related machinery in manufacturing process and would include processes such as numerically controlled machining, laser cutting, water-jet cutting and robot control. Automated Materials Handling (AMH), sometimes called automated storage/retrieval systems, involves the automated movement of items during the manufacturing process. Such systems may use high-rise stacker cranes, automated guided vehicle systems, computerized conveyors, computerized carousels, and other such systems to store and retrieve materials. Computer-integrated manufacturing (CIM) involves integrated systems of NC machines, robots, material conveyors, and other such computer-driven equipment. Robotics may involve simple pick and place robots, with 1, 2, or 3 degrees of freedom or more sophisticated robots that can handle tasks such as welding or painting on an assembly line and may also have the benefit of trajectory control (Kotha and Swamidass, 2000).

Innovation is identified as a critical driver of business productivity and economic growth (Schumpeter, 1934; Romer, 1990). Schumpeter (1934) argued that the catalyst to innovation is the transformation of knowledge into new products or processes. The relationship between innovation output and innovation inputs has been used extensively in the literature (Crepon et al., 1998; McCann and Simonen, 2005; Griffith et al., 2008.; Roper et al., 2008). Numerous scholars have attempted to explain why some firms are more likely to innovate, with firm characteristics, such as size, sector, ownership, and location being identified as influential drivers of innovation output (Audretsch and Feldman, 1996; Boschma, 2005; Gordon and McCann, 2005; Jordan and O'Leary, 2008; McCann and Simonen, 2005; Tether, 1998; Romer, 1990; Roper et al., 2008). The importance of R&D to innovation activity within firms has also been established by many authors (Roper et al., 2008; Freel, 2003). Firms engaging in R&D activity benefit their existing stock of knowledge resulting in commercial gains from the introduction of new products, processes and/ or organisational innovations (Roper et al., 2004). There is also considerable evidence of the importance of external sources of knowledge for innovation outputs (Mansury and Love, 2008). These external sources of knowledge may include linkages with customers, suppliers, competitors and/or research institutes (Bellamy et al., 2014; Love et al., 2011; Roper et al., 2008). Likewise, managerial capabilities have been highlighted as an important factor in firm level innovation. Successful innovation requires that firms and managers provide clear and consistent signals to employees about the goals and objectives of the firm (Barnes et al., 2006; Crowley and Bourke, 2016). In addition, the technologies firms adopt and use, such as AMT, can influence innovation capabilities (Santamaría et al., 2009; Raymond et al., 2009).

In recent decades, firms have made substantial investments in