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# AT THE ROOTS OF THE FOURTH INDUSTRIAL REVOLUTION: HOW ICT INVESTMENTS AFFECT INDUSTRY 4.0 ADOPTION

June 2020

Marco Fanno Working Papers – 253

# AT THE ROOTS OF THE FOURTH INDUSTRIAL REVOLUTION: HOW ICT INVESTMENTS AFFECT INDUSTRY 4.0 ADOPTION

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## ABSTRACT

The debate on the adoption of industry 4.0 technologies focuses on the transformation of organizations and business opportunities towards a new industrial revolution, driven by a recent emerging technological scenario. Despite this growing discussion, little has been said on the relationship with the previous waves of digital technologies and specifically how Information and Communication Technologies (ICT) are related with the adoption of industry 4.0 technologies. The paper explores the relationship between the antecedents driving industry 4.0 investments, examining how the firm's ICT endowment relates to the industry 4.0 technologies adopted, in terms of intensity as well as of types of ICT associated with specific types of industry 4.0 technologies, and the role of strategic motivations on the investment 4.0. Based on unique data gathered in 2017 on a sample of 1,229 Italian firms, results on 165 adopters show the positive relation between the adoption of ICT and industry 4.0 technologies as well as between specific groups of ICT technologies – that we identify into three ones: web ICT, management ICT, and manufacturing ICT – and groups of industry 4.0 ones (data-driven tech 4.0, production tech 4.0, and customization tech 4.0). Results highlight the strong connection between firm experience with prior digital investments and the consequent Industry 4.0 adoption. Moreover, there is a relation between specific clusters of ICT technologies – Web ICT, Operation ICT, and Management ICT – and industry 4.0 technologies. Among the strategic motivations driving industry 4.0 the relevant one is product variety, consistently with the selective technologies chosen, taking into account the ICT path of adoption. On the contrary efficiency is negatively related to the adoption of industry 4.0 technologies, stressing the more important role of market-driven variables for technological investments. A second relevant result is related to the role of ICT-related competences firms have to internally develop in order to adopt industry 4.0 technologies, beyond size. For firms – also SMEs – it becomes more important in the context of "Industry 4.0" to rely on internal resources (know-how connected to the ICT domain) that can positively enact the selection and exploitation of industry 4.0 technologies. As a policy implication, pushing the adoption of industry 4.0 technologies in firms with limited ICT resources should be coupled with actions supporting the development of such know-how and broader ICT competences as the roots for industry 4.0.

**Keywords:** digital technologies, ICT, strategy, industry 4.0, fourth industrial revolution

The research has been supported by the project "Manufacturing activities and value creation: redesigning firm's competitiveness through digital manufacturing in a circular economy framework" – grant n. BIRD161248/16 (University of Padova, Department of Economics and Management).

## INTRODUCTION

There is a growing attention on how new emerging technologies – from 3D printing to robotics, from big data to artificial intelligence - are enabling the rise of the fourth industrial revolution. The digital transformation can be interpreted as a disruptive phenomenon (Kenney, Rouvinen, & Zysman, 2015) transforming the rules of competitions (Christensen et al., 2016) and the rise of a new paradigm (Almada-Lobo, 2016). Firms able to exploit technological advancements to strengthen their competitive advantages can obtain superior performance.

Nevertheless, the changes in the business landscape linked to those digital technologies and identified as a "revolution" is not completely new. In the field of management discipline, the use of the expression "revolution" has marked three major moments of technological transformations, each of which is characterized by the introduction of management tools and principles that have transformed specific areas of business action. These three different technological waves have redefined, at different times, the levers and operating methods with which companies define their organizational structures and deal with the market.

The three revolutions that have marked the discipline of management since the early 90s can be summarized by highlighting the different technologies that have set in motion as many important processes of change and the areas of business that have been subject to change. In the early 1990s, a first managerial revolution took shape with the massive introduction of new technologies for integrated business management (Enterprise Resource Planning) linked to a deep reorganization of business processes (Business Process Reengineering – BPR) (Hammer & Champy, 2001; Lee, Chu, & Tseng, 2011).

A second technological revolution took shape at the end of the '90s and at the beginning of the following decade thanks to the spread of the Web as instrument for communication and commercial purposes (Armstrong & III, Hagel, 1996; Kelly, 1998; Porter, 2001). The impact of these new communication tools is mainly linked to the relationship between business and consumers: in a few years e-commerce has become increasingly important thanks to platforms that are of global importance. Moreover, the way of managing the communication processes between business and final consumer is changed thanks to new communication tools that change in a bidirectional key communication processes long managed in unidirectional form (Sawhney, Verona, & Prandelli, 2005). In this case, too, the expression “revolution” is legitimate because the new ways of organizing relations between the company and the market trigger an overall redefinition of the principles and operating practices that the marketing function had consolidated over time.

A third technological revolution has taken shape in recent years thanks to the introduction of digital technology in the field of production processes in the strict sense (Anderson, 2012). The spread of technologies for additive manufacturing (3D printers) and increasingly low-cost and autonomous robots marks a new step forward in the introduction of digital in business activities. In the debate on the paths of adoption of industry 4.0 technological solutions, studies have stressed the new implications for business activities and firm competitive advantage related with such emerging technologies. Scholars explore the rise of a new factory concept (i.e. the smart factory) and the consequent transformation of the entire organization (Holmström, Holweg, Khajavi, & Partanen, 2016). Driven by efficiency, the digital transformation of manufacturing processes allows firms to enhance internal control both through specific technologies in the production sphere – i.e. robotics – and in the data management of such processes – i.e. through sensors / Internet of Things (IoT). In addition, new technologies such as 3D printing open new opportunities to transform the scale and variety of production (Berman, 2012) with relevant consequences on production customization. Moreover, industry 4.0 technological solutions have also an important impact on innovation processes, since more and more customers can become active players in product design and product development, potentially modifying firm business models and mechanisms for value creation and appropriation (Agrifoglio, Cannavale, Laurenza, & Metallo, 2017; Bettiol, Capestro, & Di Maria, 2017; Bogers, Hadar, & Bilberg, 2016).

These new technologies have a revolutionary impact principally because they contribute to introduce new elements in business strategies, making it possible for companies to improve their efficiency (Moeuf et al., 2017) and offer higher product variety, also through the opportunity to customize their products (Bharadwaj et al. 2013). In this way, firms may achieve or maintain a strategic advantage that allows them satisfying their customers, exploiting new market opportunities (new products and new markets) and compete at international level (Leeflang, et al. 2014).

Despite the growing attention on the rise of the fourth industrial revolution (Piccarozzi, Aquilani, & Gatti, 2018; Roblek, Meško, & Krapež, 2016), limited attention has been given to understand how investments in new digital technologies (industry 4.0) are rooted on prior technological path of adoption of ICT, also disentangling the role of specific technologies on both sides. The paper aims to understanding the relationship between ICT and industries 4.0 technologies, examining the relationship between the intensity of ICT endowment and the number of industry 4.0 technologies adopted and which are the ICT more likely to be associated with specific industry 4.0 technologies. In addition, the paper explores the role of strategic motivations for “Industry 4.0” investment.

We investigate such relationship by considering ICT as strategic assets the firm adopt in order to sustain its competitive advantage (Aral & Weill, 2007), within the broad framework of the resource-based view (J. B. Barney, Ketchen, & Wright, 2011; Jay B. Barney, 1996). Prior investments in ICT can prepare and support the firm in the following technological investments, by aligning them with the strategy (Aral & Weill, 2007; McAfee, 2004).

Based on unique data gathered in 2017 on a sample of 1,229 Italian firms, results on 165 adopters show the positive relation between ICT and industry 4.0 technologies as well as between specific clusters of ICT technologies (web ICT, management ICT and operations ICT) and industry 4.0 technologies. Results highlight the strong connection between firm's know-how and skills built on prior digital investments and the consequent "Industry 4.0" adoption. Moreover, it emerges that the strategic motivations driving industry 4.0 are related to increasing product variety strategies consistently with the selective technologies chosen. Final theoretical and managerial implications are provided.

## THEORETICAL FRAMEWORK

A growing body of literature is discussing about the opportunities and challenges of industry 4.0 technologies (Liao, Deschamps, Loures, & Ramos, 2017). In the past years new digital technologies – from 3D printing to robotics, from Internet of Things to artificial intelligence – have progressively highlighted new strategic paths and redefinition of internal business processes as well as relationships within business ecosystems (OECD, 2017). Scholars have proposed the idea of a new industrial revolution (Roblek et al., 2016), which should radically transform economic activities and value generation. According to this literature, this revolution is developed into three main directions.

The first one is related to a new concept of factory (smart factory) and a profound reconfiguration of manufacturing processes (Veza, Mladineo, & Gjeldum, 2015). Through technologies such as robotics firms can increase their efficiency along with product variety up to one-to-one solutions, reducing the difference between large and small firms (Weller, Kleer, & Piller, 2015).

The second direction refers to more open processes of innovation (Chesbrough & Appleyard, 2007) and a different relationship between manufacturer and customer in product idea generation and manufacturing (Chen et al., 2015), where customers become *makers* (Anderson,

2012) reversing the order in the value chain. This perspective further enhances the role of customers – or better, users – in innovation activities across the firm boundaries with their ability to exploit their experience also for new product development (Baldwin & Hippel, 2009; Rayna & Striukova, 2016).

The third direction is rooted on data exploitation and the chance to enhance information management *via* big data analysis, artificial intelligence, and IoT solutions. Through such technological solutions firms may enhance relationships with the actors of the value chains (from suppliers to customers), also increasing their control over internal processes (Coreynen, Matthyssens, & Van Bockhaven, 2017; Huberty, 2015).

Despite the discussion on the present technological scenario as a radically new, we are interested in further exploring the linkages between this technological revolution and the introduction into firms of previous technologies that have contributed to redesign business processes and the rise of new form of enterprise (Bughin, 2008).

**Digital Technologies transforming Businesses: The scenario of ICT**

The first managerial revolution linked to the introduction of digital in companies coincides with the introduction of so-called integrated management systems as a digital infrastructure for the management of companies. These technologies represented an important technological leap forward compared to the traditional IT tools available to companies until the end of the 1980s. Up to that date, business IT had developed software solutions capable of responding to specific business functions (administration, finance, production, marketing, etc.) without it being possible to rely on shared databases and without being able to rely on simple solutions for the management of inter-functional processes. Software for integrated business management (i.e. the world leader SAP), overturned this development logic by offering a single platform with different applications for different business functions and a single reference database, transforming IT in a fundamental driver for value creation rooted in new intelligence built in the software (Micelli, 2017; Nevo & Wade, 2010).

The introduction of these integrated management solutions triggers a profound change in the functioning of the organizational dynamics of large multinational companies, through a deep transformation called Business Process Reengineering (BPR). This transformation coincides with a substantial change in the way organizations are managed, going beyond the functional organization to adopt a model structured by processes thanks to technology (Hammer and Champy, 1994). This literature explicitly highlights the radical dimension of change imposed by new technologies and proposes methods of intervention that aim to implement radically new forms of process organization.

A second important revolution in the application of digital technologies in firms is related to the Web. Since the end of the 1990s, the spread of the Internet and the changes that Internet would have triggered were thought of as the beginning of a real "New economy", with its own rules, specific and different from those that have governed the economy of the past (Kelly, 1998; Porter, 2001). There is little doubt that the rapid spread of the Web has constituted a substantial revolution in the way of doing business, particularly with regard to the relationship between business and consumer. The latter, far from being alone and isolated in its decision-making processes, can leverage digital social connections allowing a previously unknown capacity for evaluation and proposal. This knowledge contribution represents an opportunity for companies to grow and innovate (Armstrong & III, Hagel, 1996). At the same time, the Web strongly impact on the traditional distribution channels, towards a larger variety of e-commerce strategies (Gulati & Garino, 2000).

Those new business scenarios generated by ICT show a transformation in firm's internal processes as well as in the connection with the market supported by new technological infrastructures. In this perspective, they have prepared the basis for the new (fourth) revolution.

## From ICT to Industry 4.0

The digital manufacturing linked to industry 4.0 technologies is not completely new. Many of the technologies that today we consider to be enabling a new technological paradigm have actually been on the market for several years. Numerically controlled machines (CNC) were developed in the 1950s and have become part of the technological equipment of manufacturing companies. Laser cutting devices were invented in the 1970s and have been widespread in companies since the 1980s. 3D printers, in their various versions, have also been on the market since the end of the 1980s and became part of the equipment of prototyping laboratories as early as the 1990s. It is not the novelty, *stricto sensu*, of these technologies that makes them "revolutionary" but rather their low-cost diffusion, a rather recent phenomenon, and the possibility of exploiting their technological potential through relatively accessible programming tools.

Dramatic cost reduction and accessibility of technologies make it easier and "democratic" ((Thomke & von Hippel, 2002) to access sophisticated tools that can connect the world of computer design (CAD) and the world of production (CAM). It is precisely this democratic use that push new dynamics of production organization. On the one hand, they allow larger companies investing in these tools on an extensive scale compared to the past (re-launching the project of "automatic factory" that had acquired visibility at the end of the 1980s). On the other hand, also new small-sized firms can acquire such tools that were once inaccessible, impacting on their ability to compete on a wider scale (Anderson, 2012).

In his recent analysis on industry 4.0, Schneider (2018) identifies specific traits and challenges for implementation of industry 4.0 technologies *vis-à-vis* other technologies and discussion concerning digitalization within firms. In this view, digitalization can be considered as a technological prerequisite for industry 4.0, which cannot be applied without prior digital investments related to past digital revolutions. This means relying on the potentials of the Web and on IT systems to support knowledge management and business reconfiguration (Venkatraman & Henderson, 1998). Ghobakhloo (2018) provides another contribution in this direction. He discusses about the principles and conditions for an effective adoption of industry 4.0 technologies, by identifying a roadmap towards industry 4.0 (Ghobakhloo, 2018) Not all firms have the IT maturity to adopt industry 4.0 solutions. In particular the implementation of industry 4.0 technologies is related to prior IT infrastructure, but also clear IT governance and industry strategies consistent with IT development strategies.

From this perspective, IT prior investments are firm's assets to be exploited in order to positively achieve superior performance (Aral & Weill, 2007). IT infrastructure as well as IT competences within the firm become key resources the firm may leverage on in order to be more competitive. In this regards, we can state that it would be hard for firms with limited IT resources – considered both in terms of IT infrastructures and IT competences – to fully exploit the advantages provided by industry 4.0 technologies: in terms of efficiency in the adoption of new technological solutions (Holmström et al., 2016; Zangiacomi, Oesterle, Fornasiero, Sacco, & Azevedo, 2017), within a new factory concept (Reinhard, Jesper, & Stefan, 2016) and through new supply chain management strategies (Nyman & Sarlin, 2014). In additon to the IT maturity related to their ICT endowment, firms adopt industry 4.0 technologies with the aim to achieve some strategic results, folowing, therefore, their own strategy. Some of the most important strategic motivations for the implementation of industry 4.0 technologies are linked to the maunfacturing/marketing processes, such as efficiency, enhancing product variety, improving consumers' involvement in product development and production (Rayna & Striukova, 2016) and increasing the level of servitization (Cusumano, Kahl, & Suarez, 2008). Others are more generic, such as the aim to exploit new market opportunities that these technologies allow to achieve, as well as the aim to improve their competitiveness at international level (Kopsidis, & Bromley, 2016). From this point of view, industry 4.0 technologies may support the firm in strengthening its innovation process by relying on customer's knowledge and experience. At the same time, in relation for instance with IoT, the firm can further enlarge the value of products by offering additional services or even change its business model from product to service-centric value generation.

These perspectives stress the need for a better understanding of the actual relations between the large set of technologies already available within the firm and their impacts in terms of "Industry 4.0" adoption and the role of strategic motivations. To best of our knowledge, no research has been developed so far in this direction: 1) measuring empirically the connection between IT prior investments and industry 4.0 technologies, 2) taking into account strategic orientations of firms.

The new digital landscape is characterized by a large set of technologies that address multiple business needs and can be applied to different activities of the value chain (Reinhard et al., 2016; Roblek et al., 2016). Firms can select the most appropriate technology to achieve their strategic goals. From this perspective, further attention should be given to explore how the firm's ICT endowment and their strategic motivations for investing in "Industry 4.0" are linked to industry 4.0 technologies. In particular, we assume that the adoption of industry 4.0 technologies follow a previous ICT experience and depends on firm' specific strategic motivations related to the results they aim to achieve (see Figure 1).

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## EMPIRICAL ANALYSIS

### Methodology

In order to reach our research goals, we carried out a survey targeting Italian manufacturing firms of Made in Italy sectors (broadly including Automotive, Furniture and home products, Fashion) located in the North of Italy (see table 1). The focus on Italy is justified for two reasons. Firstly, in 2016 the Italian Government has promoted a "National Plan for Industry 4.0" in order to provide financial and fiscal supports to spread the adoption of industry 4.0 technologies among manufacturing firms. Secondly, firms located in North Italy have a major relevance on Italian Gross Domestic Product (GDP) and on the national competitiveness in the international markets (Lamorgese & Olivieri, 2017).

The population refer to 8,022 manufacturing firms drawn from AIDA[1] national database. We sampled firms of specific 11 Made in Italy industries (automotive, rubber and plastics, electronic appliances, lightning, furniture, eyewear, jewelry, sport equipment, textile, clothing and leather/footwear – TCF) and with an annual turnover higher than 1 Ml Euros. However, for some industries such as lightning, eyewear, jewelry and sport equipment we selected also firms with a turnover lower than 1 Ml Euros, because those industries are characterized by a strong presence of industrial districts, where even small firms can be competitive in reason of high specialization within the local value chain (Becattini, Bellandi, De Propris, 2009).

The survey is based on a structured questionnaire submitted through CAWI[2] methodology to entrepreneurs, Chief Operation Officers or managers in charge of manufacturing and technological processes. Specifically, basing on literature (Almada-Lobo, 2016), the questionnaire aimed to assess the adoption of the following industry 4.0 technologies: (1) Robotics, (2) Additive manufacturing (AM), (3) Laser cutting, (4) Big data/Cloud, (5) Scanner 3D, (6) Augmented reality (AR) and (7) Internet of Things (IoT) and Intelligent products. These

1 AIDA is provided by Bureau Van Dijk – A Moody's Analytics Company. Aida contains comprehensive financial and economic information on companies in Italy, with up to ten years of history.

2 CAWI (Computer Assisted Web Interview) methodology was selected because it is appropriate to contact a large sample. In order to interview entrepreneurs, COO or manufacturing managers we did a prescreening through information available online or through a dialogue with the firm with the aim of having, when possible, the personal email of the contact person.

technologies are those that more than others support the strategic needs of the manufacturing firms both in B2C and in B2B markets (Sanders, Sanders, Elangeswaran, & Wulfsberg, 2016). In addition to some descriptive variables, the questionnaire aimed also to assess the firm's ICT assets and the reasons underlying the adoption of the industry 4.0 technologies above mentioned.

**Sample characteristics**

From the 1,229 questionnaires collected, 205 firms declared to adopt at least one of the seven industry 4.0 technologies considered. For our analysis we selected only the firms that answered to all questions of interest. Specifically, we have taken into consideration only adopters providing information on their ICT infrastructure and the motivations of the investment in industry 4.0 technologies. We obtained 165 useful respondents. Tables 1 and table 2 report descriptive about the sample analyzed.

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As shown in the table 1, small firms (with an annual turnover lower than 10 ml of Euros) represent the 73.9% of the sample. In terms of percentage the distribution among the different industries is quite well balanced. More than the 60% are B2B firms.

Table 2 shows data on business characteristics. In particular, an average export sale composes the 45.5% of the firm's turnover, with an average of 26.4% related to the first foreign market. The firms expend (average) the 6.2% of their turnover for R&D activities. Almost the 67% of the sample produce bespoke or customizable products. Finally, most of the firms produce locally (62.7% in the Region, 29.5 in Italy) and only the 7.8% abroad; moreover, suppliers are located principally in Italy (46.8%) or in the same Region (35.7%).

Table 3 reports the frequencies about the different type of ICT firms of the sample have, the firm's motivations of investment in industry 4.0 and the different type of technologies 4.0 adopted.

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As regards ICT, it has been asked to the firms to declare which type of ICT they already have, choosing among nine different types of technologies, considered as the most used for operative and strategic goals (Bloom et al., 2014; Ramdani, Chevers, Williams, 2013): (1) website; (2) social media; (3) e-commerce, (4) CRM (Customer Relationship Management), (5) SCM (Supply Chain Management), (6) ERP (European Resource Planning), (7) MRP (Material Requirement Planning), (8) CAD/CAM (Computer-Aided Design-Computer-Aided Manufacturing) and (9) CNC (Computer Numerical Control). Website is a technology common to almost all the firms of sample (94.5%). Because website is no-discriminant variable, we decided to exclude it in the following regression analysis performed to evaluate the relationships between ICT and the industry 4.0 technologies. The majority of firms use CAD/CAM (66.7%) technology, while only 10.3% SCM.

According to the recent research (Müller, Kiel, Voigt, 2018), we have chosen the motivations strategically most important for the adoption of the industry 4.0 technologies. Such motivations refer to the: (1) improving of customer service, (2) seeking the efficiency, (3) maintain the international competitiveness, (4) have new markets opportunities (new products/new markets) and (5) increasing the products variety. They were measured through a 5-point Likert-scale form "not-at-all" (1) important to "very-much" (5) important. To estimate the frequencies we calculated a dichotomous variable using the values 4 and 5 as positive side and the others as negative. In this way, improving the customer experience and efficiency-seeking result the most important motivations for the adoption of industry 4.0 technologies.

Finally, with regard to the seven industry 4.0 technologies investigated, almost half of the sample adopted Laser cutting (49.7%), Big data/Cloud (40.0%), AM (34.0%) and the most recent IoT (24.2%) have a good adoption rate, instead the less adopted is the AR (13.3%).

In the next paragraphs, we present the type of analyses performed to reach our research goals and results of the analyses about the relationships among ICT, motivations of adoption, and industry 4.0 technologies.

**Results**

To explore the relationship between the firm's ICT endowment and the industry 4.0 technologies adopted by the firm, as well as the role that motivations may have in this relationship, we performed a set of analyses following a stepwise design. As first step of analysis, we estimated, for the sample, the firm's ICT endowment (sum of ICT) and the firm's intensity of industry 4.0 (sum of industry 4.0 technologies adopted). As tables 4 shows, more than the 70% of firms have more than one ICT and almost the 64% of them have adopted more than one industry 4.0 technology.

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Such result suggests that a large part of sample firms has a multiple technology asset and, therefore, rather than evaluate the relationships among the single technologies, it seems to be more interesting evaluating if the firm's ICT endowment (intensity) positively influences the intensity of industry 4.0 technology adopted and the existence of linked technology (ICT and 4.0) groups. In this sense, we estimated the existence of relationship between the firm's ICT endowment (sum of ICT as independent variable) and the intensity of industry 4.0 (sum of industry 4.0 technologies adopted as dependent variable) through a linear regression, with firm size (turnover) and market (B2B-B2C) as control variables. Results reported in table 5 show that firm's ICT endowment has a positive relationship ($p < 0.001$) with the intensity of technologies 4.0 adopted and that this relation depends neither from turnover nor from the type of market. Higher is the number of ICT firms have, probably higher will be the number of technologies 4.0 they adopt.

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Confirmed the above-mentioned relationship, we proceeded to evaluate the role that strategic motivations have for the investment in industry 4.0. In doing so, we performed a set of analyses, considering, step-by-step, only one motivation in each regression analysis and, finally, the complete model with the five motivations considered all together. As shown in the table 6, even if firms declared that the most important motivations of investment in industry 4.0 are *customer service* and *efficiency*, these two motivations taken singularly do not influence the intensity of technologies 4.0 adopted. Moreover, if these two motivations are taken into consideration with the other main strategic motivations (model 6), results show that efficiency has a significantly negative ($B$ = -.169, $p < .05$) impact. The model 6 shows also that considering all together the five strategic motivations of adoption, the most important is the willingness to increase the *products variety*: the only motivation that has a significantly positive ($B$ = 185, $p < .05$) influence on technologies 4.0 adoption. These results are very interesting because they stress that in the context of the fourth industrial revolution in order to reach production and market results firms need to use combinations of these types of new technologies (Schneider, 2018).

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The results about the high number (frequencies) of the sample firms that have more than one ICT and have adopted more than one technology 4.0 – linked to the result about the positive relationship between the intensity of ICT and the intensity of technologies 4.0 – allow us to verifying the existence of technologies groups through a factor analysis. Both variables - the ICT endowment (8 items, as the types of ICT investigated, with two values: 0 = No ICT and 1 = Yes ICT) and the Industry 4.0 technologies adopted (7 items, as the type of technologies 4.0 object of the analysis, with two values: 0 = Technology 4.0 no-adopted; 1 = Technology 4.0 adopted) - are dichotomous variables[3]. Table 7 reports the rotated factor loadings about ICT. Instead, table 8 reports the rotated factor loadings concerning Industry 4.0 technologies.

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[3] In this case, the factor analysis using tetrachoric correlation with principal components extraction is the best way to calculate factors that group the different items (Ferrando, Lorenzo-Seva, 2017). The Bartlett measure of each factor analysis is significantly ($p < 0.001$) different from zero, indicating, therefore, that the factor analysis is appropriate for these data (Battisti, Stoneman, 2010).

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As regards ICT, the factor analysis highlight three different factors that group the ICT investigated with an acceptable percentage of total variance explained (71.7%). The first factor includes all ICT technologies – CRM, SCM, ERP and MRP – used to manage relationships, activities, or processes both internally and externally to the organization. We named such factor as *Management ICT*. The second factor contains CAD/CAM and CNC. These types of ICT have the function to support the manufacturing and production processes, from the design to the planning and optimization (Newman, Allen, Rosso, 2003). In this sense, considering also the sample of manufacturing firms, we considered appropriated the name of *Manufacturing ICT*, for their supporting role to the manufacturing/production activities (Benzi, 2017; Majstorovic, 2014). We named the third factor emerged from the analysis as the *Web ICT*, being composed by Social media and E-commerce

Table 8 highlights the three groups of Industry 4.0 technologies emerged from the factorial analysis, also in this case with an acceptable percentage of total variance explained (67.6%). First factor includes Robotics and Augmented Reality (AR), two Industry 4.0 technologies principally used for production purposes (robotics to produce, AR to support assistance and other related activities). For this reason, we named this group as *Production Techs 4.0*. The second group includes the technologies 4.0 typically used to improve the customization of products, such as AM, Laser cutting and Scanner 3D. We named this group as *Customization Techs 4.0*. Finally, the third factor comprises Big data/Cloud and IoT. These technologies 4.0 allow firms managing data, thus we named the factor *Data-driven Techs 4.0*.

Based on those groups, we analyze the relationships between each different ICT and Industry 4.0 technologies groups emerged from the factor analysis as well as the evaluation of the influence that the five motivations investigated may have on the Industry 4.0 technologies groups. In particular, the first analysis will provide evidence of any path dependence between groups. To test these relationships and influences we tested two regression models (taking into consideration the sum of technologies included in each group considered). Table 9 reports the results of the analyses.

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In the model 1, we regressed the three ICT groups (*Web*, *Management* and *Manufacturing*) on each one of the three Industry 4.0 technology groups (*Production*, *Customization* and *Data-driven*). The group of *Manufacturing ICT* positively influences ($B$ = .304; $p < .001$) the adoption of *Customization Techs 4.0*. Using both CAD/CAM and CNC probably influenced the adoption of more than one technology 4.0 such as AM, Laser cutting and Scanner 3D. The positive relationship between these two groups of different technologies may depend by the use purposes. Indeed, all these technologies are suitable to compose a technology asset for the products customization.

Instead, regard the *Data-driven Techs 4.0* the Management ICT have probably influenced ($B$ = .393; $p < .001$) the adoption of Big data/Cloud and IoT. These two types of Industry 4.0 generate data useful for different purposes, from production to market and customer satisfaction, therefore the link with CRM, SCM, ERP and MRP technologies might related just to the same operative and strategic goals.

Finally, the group of *Production Techs 4.0* is not influenced by any particular ICT group. Robotics and AR are two types of Industry 4.0 technologies mainly used to improve the production processes and, for these reasons, might be independent from the ICT we taken into consideration. The only variable that has an influence on the group is the type of the market firms are dealing with. B2B firms have significantly adopted these two types of technologies 40 more than the B2C firms. The type of market, instead, has no influence on *Customization* and *Data-driven Techs 4.0* as well as firm turnover does not influence any of the three groups of Industry 4.0 technologies.

In the second regression model, we introduced the five motivations of investment in "Industry 4.0". Results confirm the relationships of *Manufacturing ICT* and *Management ICT* respectively with *Customization Techs 4.0* and *Data-driven Texchs 4.0*. The Market (B2B) continues to be important only for the adoption of *Production Techs 4.0* as the firm's turnover seems to be not so relevant for the adoption. It emerges also that different motivations are linked to different groups of Industry 4.0 technologies.

These results show that there is a strong link among ICT, Industry 4.0 technologies and strategy, being all those variables related, in different way, to the firm's customization processes. Finally, the firms that want to improve their customer services probably will adopt technologies 4.0 such as Biga data/Cloud and IoT. Even those results highlight the link between technologies and firm's strategy.

## DISCUSSION

The result of the regression shows a strong statistical correlation between the intensity of ICT and the intensity of Industry 4.0 technologies. The more a firm adopted ICT in the past, the higher the probability it adopts Industry 4.0 technology now. From this perspective we can maintain ICT are the basis upon which "Industry 4.0" are installed and then used. At least for Italian manufacturing firms, ICT could be considered as an antecedent of Industry 4.0 technology investments. We support that, by using ICT, firms learn the logic and rules of digitalization of business processes and activities, which will be further applied to operations and product customization with the help of Industry 4.0 technologies. In this view, the cumulative effect is due to a learning process that enriches the capabilities of the firm in taking advantage of new possibilities offered by digital technologies. As we observed from the regression, this result is not influenced by the size of the firm or – in some cases – by the typology of market (B2C or B2B), on the contrary it seems to be connected to the specific technological investments.

Our interpretation could be supported by the fact that the initial selection of ICT and therefore of industry 4.0 technology is driven by a strategic intent. The factor analysis showed that the investments in ICT could be divided in three main groups that correspond to the three main waves of managerial revolutions. The first factor, labeled Management ICT, is composed of technologies such as CRM, SCM, ERP and MRP. All those technologies respond to the need of redesigning the processes of the firm both internal and external, with the supply chain or with the customer. From this perspective, we could say that the first factor is composed of a coherent package of technologies with the intent of re-engineering business processes (Hammer and Champy, 1994).

The second factor, defined Web ICT, is composed of Social Media and E-commerce that are both connected with the evolution of the internet and the rise of the New Economy. Those technologies help firms organize new form of communications with consumers that are more effective, the quality and number of contents could be increased (images, video, text), and less expensive than traditional mass media: advertising is more affordable, even for small firms, because it is possible to target consumers in a more precisely fashion.

The third factor, labeled Manufacturing ICT, contains two technologies: CAD/CAM and CNC. Those technologies are adopted in order to have a more flexible production without losing efficiency. Although they are quite old and well-established technologies, they are still important in order to have a more customized production, a strategic need for Italian manufacturing firms that are focused on niche and personalized products.

A similar approach is evident also in Industry 4.0 technologies. The factor analysis presents three different groups. The first is related to technologies such as robotics and AR that are mainly used at the factory level both for increasing the flexibility of production and the quality of service (maintenance, access to information regarding machines). The second factor is composed by technologies dedicated to product customization, such as additive manufacturing, laser cutting and 3D scanning. Those technologies are used to translate the information gather through interaction with the customer into a customized product. The third factor is focused on data and is composed of big data, cloud computing and IoT. Those are relatively new technologies that amplified the capabilities of the firm to gather (IoT), access (cloud computing) and to analyze data (big data). The opportunity to use sensors and other digital devices could transform traditional (textile, lighting, furnishing, etc.) into smart products improving the quality and quantity of data firms could collect about the use of the product by consumers and its behavior in different conditions. Cloud computing made easier for firm to manage the increasing amount of data accumulated through internal process and interaction with external entities (other firms, consumers, institutions, smart products, etc.). Eventually big data technologies help firms to discover latent patterns on the data gathered through different inputs. All those technologies (ICT and industry 4.0) respond to specific strategic needs and fit well with the evolution paths of managerial practices described in the theoretical section. This is even clearer if we consider the motivations that are at the base of investments in industry 4.0. In particular, firms that are investing more in industry 4.0 are driven by the research of product variety and not by efficiency, which is even negatively correlated. In the race for productivity, firms chose to compete focusing more on increasing the output (product variety) than on reducing the input (efficiency). This result seems counterintuitive if we consider that efficiency (cost reduction) is at the base of every technological revolution that change the cost structure of manufacturing (Allen & Scott Morton, 1994). But if we dig more, we gather a clearer and more coherent picture.

If we combine the groups of ICT (the once obtained by the factor analysis) and the motivations of investments in industry 4.0 with the group of Industry 4.0 technology, we have more insights for understanding firms behavior (see Table 9 and figure 2).

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Insert figure 2 here

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The firms invest in production technology 4.0 (robotics and augmented reality) with the aim of improving international competitiveness and finding new market opportunities. In order to be competitive in complex international markets, firms need to be more reliable and to have new capabilities that robotics and augmented reality can offer such as: reproducibility of results, reduced defectiveness, effective maintenance. As a matter of fact, “production technology 4.0” are not statistically correlated to the three groups of ICT and seem to be independent from previous investment in ICT. We could say that those technologies add new features and capabilities to firms’ assets. On the contrary, “customization technology” (additive manufacturing, laser cutting, 3D scanning) are strongly correlated with operation ICT (CAD/CAM and CNC) and product variety as a motivation while are negatively correlated with efficiency. From this perspective, previous ICT investments are combined with new opportunities offered by industry 4.0 technology that are suited for product customization. The firms are able to strengthen their strategy of differentiation focusing on more personalized product through a combination of software and hardware. Data driven technology (Big Data, IoT) is strongly correlated with Management ICT (CRM, SCM, ERP, MRP) and customer service as motivation of investment. The firms combine the infrastructure previously built for managing information with the new opportunities offered by industry 4.0 such as new analytical tools (Big Data) and hardware devices (sensors). The information management started with the first wave of ICT is now completed through new implementations.

## CONCLUSION AND LIMITATIONS

Based on original data and extensive empirical analysis, our research shows a positive correlation between ICT investments and industry 4.0 adoption. This correlation is even more evident if we analyze in detail the different components of both ICT and “Industry 4.0”. We observed a specific combination of those technologies that has two rationales. The first is technical: there is strong coherence in the combination of old (ICT) and new (industry 4.0) technologies. For example, data driven technology has its roots in previous investments in solutions implemented for information management and business process reengineering. The second is more strategic: the firms tend to adopt technology that strengthen their positioning in the market in terms of product differentiation that is one of the most important competitive advantage of Italian manufacturing firms in global markets. In general, we observe several bonds between “Industry 4.0” and the first waves of ICT implementation. The fruits of “Industry 4.0” have strong roots into the ground of ICT.

From a managerial point of view our study suggests a stronger link between previous business revolutions driven by technologies and the fourth industrial one than evidence already available and discusses so far. Firms that have already being trained in coping with technological and business challenges in the past are those more ready to exploit the next technological wave for business opportunities. At the same time, our results also highlight the path dependence among groups of technologies, where specific investments (i.e. in Web ICT) then bring firms following the adoption of related industry 4.0 technologies. This could be seen a positive but also a negative outcome of having internal ICT resources in the context of “Industry 4.0”.

A second relevant result of our research is related to the role of ICT-related competences firms have to internally develop in order to adopt industry 4.0 technologies. It is not a matter of size *per se*. Rather, for firms – also SMEs – it becomes more important in the context of "Industry 4.0" to rely on internal resources (know-how connected to the ICT domain) that can positively enact the selection and exploitation of industry 4.0 technologies. In this perspective, also as a policy implication, pushing the adoption of industry 4.0 technologies in firms with limited ICT resources should be coupled with actions supporting the development of such know-how and broader ICT competences as the roots for industry 4.0.

Our research has some limitations. The first one is about the sample that is limited to North of Italy. In order to further test our results, we should take into consideration other regions, at least in Europe. The second limitation is that we have cross-section data (based on 2017) and industry 4.0 is a dynamic phenomenon that could be fully analysed in its consequence on a longer period of time. We are aware of the fact that we should implement another survey in the next few years in order to compare results.

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**FIGURE 1**

**Conceptual model**

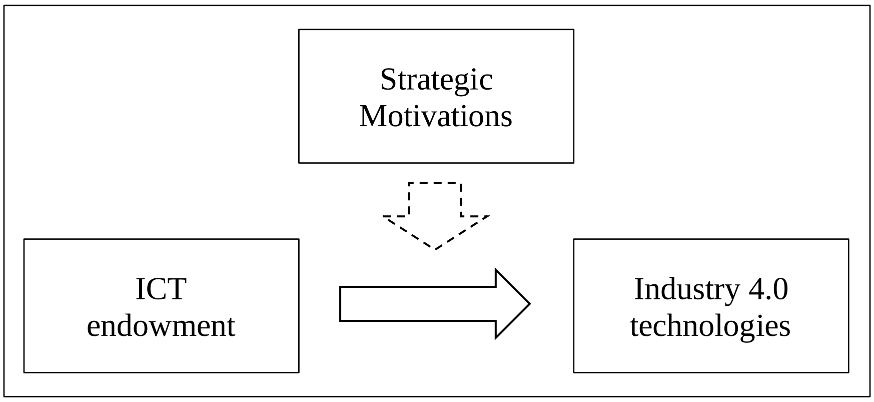

**FIGURE 2**

**ICT groups & motivations of investment on technologies 4.0 groups**

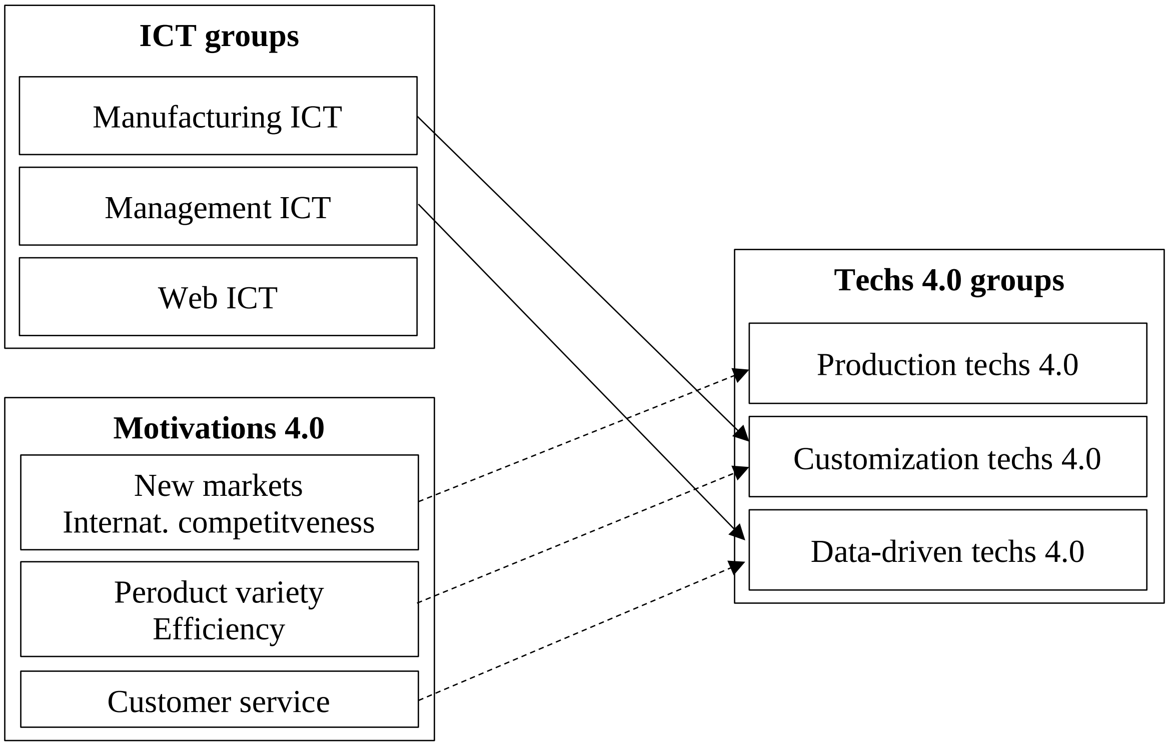

**TABLE 1**

**Descriptive statistics of the sample**

| | |
|---|---|
| **Firm' size (EU revenue class)** | |
| Micro firms (<2mln) | 31,5% |
| Small firms (2mln<€<10mln) | 42,4% |
| Medium firms (10mln<€<50mln) | 20,6% |
| Large firms (>50mln) | 5,5% |
| **Industry** | |
| Furniture | 17.0% |
| Automotive | 12.7% |
| Clothing | 12.7% |
| Electrical Motors and parts | 10.3% |
| Lighting | 9.1% |
| Eyewear | 9.1% |
| Leather/Footwear | 8.5% |
| Jewelry | 7.9% |
| Textile | 6.7% |
| Rubber and plastic goods | 4.8% |
| Sport equipment | 1.2% |
| **Market** | |
| B2B | 61.2% |
| B2C | 38.8% |

Note: N = 165

**TABLE 2**

**Characteristics of adopting firms**

| | |
|---|---|
| Turnover (average 2016) | 11,982 Ml Euro |
| Employees (average 2016) | 59.66 total<br>36.4 in operations<br>4.4 in R&D<br>2.5 in marketing |
| % Export on turnover (average 2016) | 45.5% (first export market: 26.4%) |
| R&D expenditure (% on turnover) | 6.2% |
| Production output | 47.3% bespoke products<br>33.1% standard products<br>19,6% customizable products |
| Production location (value) | 62.7% Region<br>29.5% Italy<br>7.8% Abroad |
| Supplier location<br>(% on total number of suppliers) | 35.7% Region<br>46.8% Italy<br>17.5% Abroad |

Note: N = 165.

**TABLE 3**

**Frequencies of technologies and motivation of investment on Industry 4.0**

| **ICT** | **Frequencies (%)*** |
|---|---|
| Website | 156 (94.5%) |
| CAD/CAM | 110 (66.7%) |
| Computer numerical control (CNC) | 76 (46.1%) |
| Social media | 73 (44.2%) |
| Enterprise Resource Planning (ERP) | 45 (27.3%) |
| Customer Relationship Management (CRM) | 39 (23.6%) |
| E-commerce | 38 (23.0%) |
| Material Requirement Planning (MRP) | 35 (21.2%) |
| Supply Chain Management (SCM) | 17 (10.3%) |
| **Motivations of investment in industry 4.0 technologies** | **Frequencies (%)**** |
| Customer Service | 60.6% |
| Efficiency | 56.4% |
| International competitiveness | 46.7% |
| New markets | 41.8% |
| Products variety | 37.0% |
| **Industry 4.0 Technology adopted** | **Frequencies (%)*** |
| Laser cutting | 82 (49.7%) |
| Robotics | 77 (46.7%) |
| Big Data/Cloud | 66 (40.0%) |
| Additive manufacturing (AM) | 57 (34.5%) |
| Internet of Things (IoT) | 40 (24.2%) |
| Scanner 3d | 34 (20.6%) |
| Augmented reality (AR) | 23 (13.3%) |

Note: N = 165; *Multiple choices; **Measured on a 5-points Likert-scale, to obtain a dichotomous variable, the values 4 (much) and 5 (very much) were transformed in 1 (yes) and the rest in 0 (no).

**TABLE 4**

**Technologies intensity**

| **Industry 4.0 Technologies intensity** | **Frequencies (%)** |
|---|---|
| One Industry 4.0 technology | 60 (36.4%) |
| Two Industry 4.0 technologies | 51 (30.9%) |
| Three Industry 4.0 technologies | 22 (13.3%) |
| Four/more Industry 4.0 technologies | 32 (19.4%) |
| **ICT intensity (without website)** | **Frequencies (%)** |
| No ICT | 17 (10.3%) |
| One ICT | 28 (17.0%) |
| Two ICT | 40 (24.2%) |
| Three ICT | 36 (21.8%) |
| Four ICT | 21 (12.7%) |
| Five/more ICT | 23 (13.9%) |

Note: N = 165.

**TABLE 5**

**Regression between ICT endowment and intensity of Industry 4.0 technologies**

| | **B** | **Std. Dev.** | **Beta** | **t** | **Sig.** |
|---|---|---|---|---|---|
| ICT endowment | .345 | .061 | .425 | 5.698 | .000 |
| Turnover | .169 | .177 | .071 | .958 | .339 |
| B2B-B2C | -.322 | .204 | -.112 | -1.579 | .116 |
| Constant | .893 | .620 | - | .1440 | .152 |

Note: N = 165; $R^2$ = .206.

**TABLE 6**

**Linear regression intensity of ICT & Motivations on intensity of Industry 4.0 technologies**

| Independent variables | Model 1[a] | Model 2[b] | Model 3[c] | Model 4[d] | Model 5[e] | Model 6[f] |
|---|---|---|---|---|---|---|
| Sum of ICT | .432*** | .372*** | .384*** | .382*** | .393*** | .356*** |
| Efficiency | -.040 | - | - | - | - | -.169* |
| Products variety | - | .220** | - | - | - | .185* |
| New markets | - | - | .183** | - | - | .080 |
| Intern. competitiveness | - | - | - | .176** | - | .151^ |
| Customer service | - | - | - | - | .103 | -.009 |
| **Control variables** | | | | | | |
| Turnover | .074 | .099 | .112 | .070 | .087 | .124^ |
| B2C-B2B | -.116 | -.128 | -.107 | -.126^ | -.103 | -.154^ |

Note: N = 165; *** $p < .001$; ** $p < .01$; * $p < .05$; ^ $p < .10$; [a] $R^2 = .208$; [b] $R^2 = .252$; [c] $R^2 = .238$; [d] $R^2 = .235$; [e] $R^2 = .216$; [f] $R^2 = .288$.

## TABLE 7

**Rotated factor loadings ICTs**

| **ICTs** | **Factor 1 (*Management ICTs*)** | **Factor 2 (*Manufacturing ICTs*)** | **Factor 3 (*Web ICTs*)** |
|---|---|---|---|
| Social media | - | - | 0.883 |
| E-commerce | - | - | 0.855 |
| CRM | 0.635 | - | - |
| SCM | 0.857 | - | - |
| ERP | 0.834 | - | - |
| MRP | 0.769 | - | - |
| CAD/CAM | - | 0.873 | - |
| CNC | - | 0.916 | - |

Note: loadings lower than absolute 0.500 omitted; % of total variance explained = 71.7%.

**TABLE 8**

**Rotated factor loadings Industry 4.0 Technologies**

| **Technology 4.0** | **Factor 1 (*Production Techs 4.0*)** | **Factor 2 (*Customization Techs 4.0*)** | **Factor 3 (*Data-driven Techs 4.0*)** |
|---|---|---|---|
| Robotics | 0.761 | - | - |
| Additive manufacturing | - | 1.116 | - |
| Laser cutting | - | 0.510 | - |
| Big data/Cloud | - | - | 0.767 |
| Scanner 3D | - | 0.931 | - |
| Augmented reality | 0.925 | - | - |
| Internet of Things | - | - | 0.799 |

Note: loadings lower than absolute 0.500 omitted; % of total variance explained = 67.6%.

**TABLE 9**

**Linear regressions ICTs groups–Motivations on Industry 4.0 technologies groups**

| **Independent variables** | **Production Techs 4.0** | | **Customization Techs 4.0** | | **Data-driven Techs 4.0** | |
|---|---|---|---|---|---|---|
| | ***Model 1*** [a] | ***Model 2*** [b] | ***Model 1*** [c] | ***Model 2*** [d] | ***Model 1*** [e] | ***Model 2*** [f] |
| Web ICT | .076 | .045 | .029 | .002 | .052 | .022 |
| Management ICT | .084 | .074 | .094 | .100 | .393*** | .367*** |
| Manufacturing ICT | .109 | .031 | .304*** | .289*** | -.046 | -.052 |
| Efficiency seeking | - | -.068 | - | -.173* | - | -.067 |
| Products variety | - | .000 | - | .288** | - | -.035 |
| New markets | - | .228* | - | -.008 | - | .006 |
| International competitiveness | - | .264** | - | .082 | - | -.076 |
| Customer service | - | -.097 | - | -.124 | - | .245** |
| **Control variables** | | | | | | |
| Turnover | .095 | .127 | -.026 | -.001 | .069 | .108 |
| B2C-B2B | -.187* | -.228** | .019 | -.037 | -.042 | -.015 |

Note: N = 165; *** $p < .001$; ** $p < .01$; * $p < .05$; [a] $R^2 = .077$; [b] $R^2 = .184$; [c] $R^2 = .111$; [d] $R^2 = .188$; [e] $R^2 = .179$; [f] $R^2 = .225$.