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Emerald Journal of Manufacturing Technology Management

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Journal:	*Journal of Manufacturing Technology Management*
Manuscript ID	JMTM-09-2023-0395.R4
Manuscript Type:	Article
Subject Keywords:	Industry 4.0, Manufacturing strategy
Theoretical Context Keywords:	Type of country - developed country, Data analysis method - simple statistical analysis (eg structural equation modeling such as partial least square)
Methodology Keywords:	Data analysis method - simple statistical analysis (e.g. structural equation modeling such as partial least square), Data collection method - survey (in-person interviews and written questionnaires)

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Abstract

Purpose. Literature verifies that Industry 4.0 allows SMEs to improve global markets strategies. The paper explores the effects of Industry 4.0 on different export dimensions in manufacturing SMEs.

Methodology. The analysis is carried out on a statistically representative sample of 2,972 Italian manufacturing SMEs in 2022. The study measures Industry 4.0 as higher number of 4.0 technologies adopted. Export is analyzed in five dimensions, namely: exporting status; export regularity; newness of exporting status; export intensity; export growth. The analysis carries out five regressions controlled for a set of variables on factors that may influence SMEs' propensity to 4.0 transformation and export.

Findings. The results verify the existence of several positive and statistically significant effects of Industry 4.0 on different export dimensions. In particular, SMEs adopting 4.0 technologies obtain an increase on export intensity considered as share of foreign sales on total sales.

Practical implications. The study supports the need for managers to align their technological investments and export strategies, suggesting that a synergistic implementation enhances effectiveness in terms of SMEs integration in global markets.

Limitations. Industry 4.0 requires significant investments and resource allocation that should be considered in future studies in addition to moderating effects and cross-countries analysis.

Originality. The originality of the study lies in empirically testing that Industry 4.0, highly based on digitalization, goes further that by improving through strategic and operational changes the impact on SMEs' export, and opening up to future research, exploring the mechanism of this complex phenomenon.

Keywords: Industry 4.0, Fourth industrial revolution, SMEs, Export, Manufacturing, Exporting status, Export regularity, Newness of exporting status; Export intensity, Export growth, Quantitative studies, Regression model

Quick Value Overview

Interesting because:

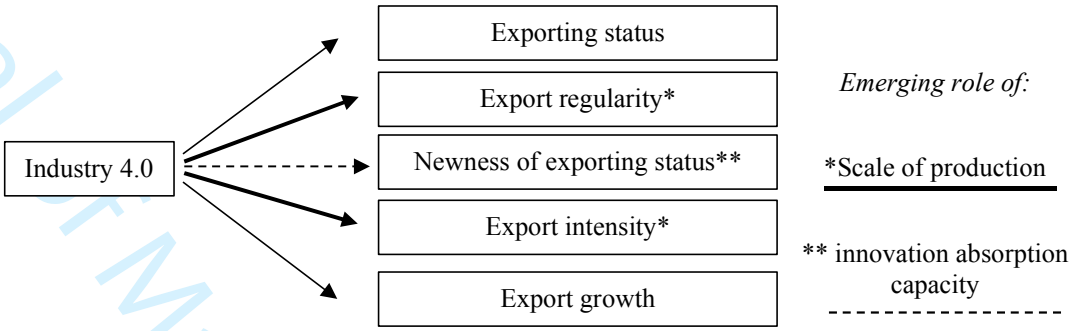
To analyze the effects of Industry 4.0 on SMEs' export is topical since SMEs, characterized by foreign and smallness liabilities, are facilitated by overcoming their main limitations in global competitiveness. However, empirical works on factors affecting firms' export remain misunderstood and very few studies explore the specific role of Industry 4.0, mainly as digitalization of operations. The study originally fills this gap measuring Industry 4.0 as gradual adoption of an increasing number of technologies.

Theoretical value:

The results show that the positive impact of Industry 4.0 is stronger for export intensity and export regularity and fewer for newness of exporting status. Hence, the study originally verifies that Industry 4.0 – requiring high initial investments – expands the scale of production mainly affecting SMEs already working for export in increasing their impact on international markets, while SMEs approaching export for the first time have issues in absorbing at the same time new technologies and information on new markets.

Practical value:

The study raises SMEs managers' awareness to adopt gradually an increasing number of 4.0 technologies increasing export, suggesting to jointly consider strategies for technological innovation and foreign expansion taking in mind the role of innovation absorption capacity. This also reveals to policy makers that entering export markets doesn't require heavy need for government intervention, suggesting to make a choice in the direction to incentivize more innovation policies rather than internationalization policies because of their dual positive impact on SMEs.



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1. Introduction

Governments around the world are encouraging SMEs to introduce artificial intelligence, blockchain, x-reality and, more generally, technologies of the Fourth Industrial Revolution into business processes (Castagnoli et al., 2022). Implementing a mix of 4.0 technologies, through data collection and analysis and information communication, enables to:

- safeguard real-time cybersecurity (Büchi et al., 2020);
- simplify operational processes (Frank et al., 2019);
- reduce the execution time of repetitive tasks (Dalenogare et al., 2018);
- create new business opportunities (Frank et al., 2019);
- adapt strategies to global markets improving performance (Azar and Ciabuschi, 2017).

Literature on Industry 4.0 shows how business process transformation enables changes in firms' internationalization strategies (Luo and Zahra, 2023) by impacting: international competitiveness (Dzwigol et al., 2020); organization of global value chains (Lee et al., 2023); international collaboration (Götz, 2020); and the ways of entering foreign countries (Cho et al., 2022; Naglič et al., 2020).

It is relevant to understand whether SMEs, characterized by foreign and smallness liabilities, may be facilitated in global market integration and market strategies by Industry 4.0, overcoming their main limitations in global competitiveness.

Despite the plethora of studies on SMEs' export, empirical works on factors affecting firms' entry to export markets remain misunderstood (Haddoud et al., 2021; Mansion and Bausch, 2020), and very few studies explore the specific role of Industry 4.0, highlighting a relevant and positive impact on export (Naglič et al., 2020). Moreover, literature on Industry 4.0 and export in SMEs analyses Industry 4.0 as digitalization of operations (Naglič et al., 2020), while literature on Industry 4.0 and performance suggests to measure it as adoption of an

increasing number of technologies (Dalenogare et al., 2018; Cugno et al., 2022) generally implemented in a phased manner (Frank et al., 2019).

The paper aims to analyze the effects of Industry 4.0 on different export dimensions in manufacturing SMEs in a developed country.

This is relevant since SMEs play a pivotal role in the development of a country and are considered the backbone of national economies (Morais and Ferreira, 2020), representing 90% of total firms (i.e. OECD, 2018) and more than 1/3 of products world trade (OECD, 2018). SMEs increase their internationalization with greater speed and breadth, and obtain more than 50% of total revenues from foreign countries (OECD, 2018). SMEs normally initiate their internationalization through exporting (Haddoud et al., 2021; Morais and Ferreira, 2020) because it is the approach implying the lowest commitment to external markets (Korsakienė and Tvaronavičienė, 2012).

The study uses a statistically representative sample of 2,972 manufacturing SMEs in Italy in 2022, corresponding to 2.3% of the universe of Italian population in terms of firms and 4.8% in terms of employees. Italy ranks ninth in the world for export in the manufacturing industry and third in the European Union after Germany and France (OECD, 2018). In addition, Italy ranks first in the number of SMEs manufacturing in Europe with 376,343 firms (Eurostat, 2019).

The paper offers three main theoretical contributions. First, it operationalizes the concepts of Industry 4.0 and different export dimensions. Second, it enriches existing quantitative studies on the topic by improving the sample from a geographical, industrial, technological and dimensional perspective. Third, it verifies the impact of Industry 4.0 on different export dimensions.

The results may support managers in the planning and management of SMEs' export, and policy makers in the development of policies to support the competitiveness of SMEs by

combining acceleration of Industry 4.0 with export activities. The results provide insight on whether the implementation of a large number of 4.0 technologies can enable SMEs to increase export. This effect, however, must be evaluated in the light of the high investments required in 4.0 technologies adoption and strategic-operational business transformation. To overcome this limitation, worldwide government actions and fiscal incentives encourage the development of SMEs and improve their technological innovation toward an Industry 4.0 approach that enables them to integrate into global markets effectively.

The paper is structured as follows. Section 2 reports theoretical background and defines research hypotheses. Section 3 describes sample, variables operationalization, and quantitative models. Section 4 reports findings and Section 5 discusses it. Section 6 highlights promising theoretical and practical implications, identifies limitations, and proposes future research directions.

2. Theoretical background and hypotheses development

2.1. Effects of Industry 4.0 on export

Literature on Industry 4.0 and export mainly focuses on how each technology might support export strategies. Figure 1 summarizes for each 4.0 technology its effects on export strategies highlighted by different Authors.

"Table 1 about here"

More efficient production techniques, such as additive and advanced manufacturing, help exporting firms to respond to technological and environmental changes in highly competitive global markets (Kafouros et al., 2008; Zahra and Covin, 1995). Zhang et al. (2023) find that robot adopters are more likely to enter export markets and improve export performance, reducing variable production costs.

Big data allows a change in export strategies through high-speed connectivity. As highlighted by Strange and Zucchella (2017), in fact, firms adopting big data are able to monitor emerging trends and opportunities in overseas markets without the need to make substantial resource commitments in local marketing affiliates, and they will be able to more effectively optimize their supply, production, and distribution activities around the world. AL-Khatib (2023) supports a positive relationship between big data analytics capabilities and export performance in the manufacturing sector in Jordan.

The empirical study by Xu and Tian (2023) verifies that artificial intelligence improves export product quality by boosting resource allocation efficiency and information-processing abilities. Brynjolfsson et al. (2019) find that the introduction of machine translation based on artificial intelligence significantly increases export allowing a substantial reduction in translation costs and helping in dealing with language barriers.

Blockchain has a positive effect on export performance, highlighting the pivotal role of technology in fostering international trade success (Purwaningsih et al., 2024).

Cloud computing increases export performance indicators – such as export value, export intensity and export in most dynamics sectors – in Italian firms, as empirically verified by Boccia et al. (2022).

As verified by Azar and Ciabuschi (2017), SMEs can better integrate into global market strategies through a more accurate export strategy adopting a larger number of 4.0 technologies. This effect is due to the fact that the implementation of Industry 4.0 in SMEs develops an environment of communication realized through cyber-physical systems. The latter are able to ensure within and beyond SMEs boundaries:

1. interconnection of any physical or virtual network element – people, means of production, plants, enterprises and partners (Büchi et al., 2020);

2. interoperability of production, knowledge exchanges, and expertise (Büchi et al., 2018).

This is achieved through technological solutions in addition to the aforementioned additive and advanced manufacturing, big data, artificial intelligence, blockchain, and cloud computing, namely:

- internet of things, smart devices and sensors that facilitate the communication of data and information between people, products and machines (Castagnoli et al., 2020);
- vertical and horizontal integration, devices enabling marketing and monitoring through real time location system, automated handling, warehouse management, human-machine interface (Del Giudice et al., 2019).
- machine learning, systems that learn or improve performance based on data (Shetewy et al., 2022);
- simulation, solutions creating scenarios in complex environments to facilitate decision making by evaluating performance estimation (Büchi et al., 2020);
- x-reality, equipment enabling sensory perception enriching, decreasing or realizing virtual environments accompanied by sound, auditory, olfactory and tattily stimuli, with possible impacts on product redesign for global markets (Del Giudice et al., 2019);
- cyber security, systems protecting information flows exchanged across globally interconnected business systems (Büchi et al., 2020).

The benefits of applying these technologies might have repercussions on the management of global markets, although their direct impact on export strategies have not yet been highlighted in the existing literature.

2.2 Hypotheses development

Existing studies on the effects of Industry 4.0 on export (Naglič et al., 2020; Valaskova et al., 2022) consider Industry 4.0 as adoption of individual 4.0 technologies. Given that Industry

4.0 is not a monolithic block (Frank et al., 2019), however, it is essential to measure it as an increasing number of technologies adopted. Moreover, the adoption of 4.0 technologies does not necessarily have to occur simultaneously, but rather can and should preferably occur gradually (Frank et al., 2019), allowing a greater integration into processes. In addition, the adoption of more technological innovations enables SMEs to export, allowing them to adapt strategies to new foreign environments and improving their performance (Azar and Ciabuschi, 2017).

It is therefore necessary to understand whether Industry 4.0, considered as gradual adoption of an increasing number of 4.0 technologies, positively impacts the different dimensions of export.

Exporting status is the dimension studied more deeply (Haddoud et al., 2021), considering whether the firm exports (positive exporting status) or not (no effect in exporting status) in a certain period of time (Pickernell et al., 2016; Hagsten and Kotnik, 2017; Cassetta et al., 2020). As highlighted by Sarbu (2022), the exporting status and firms' propensity to innovate in Industry 4.0 are strongly and significantly related. Therefore, the following hypothesis is derived:

HP1 – SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have a positive exporting status at the same given time.

A second dimension of export is the export regularity, measuring whether the firm is non-exporter, sporadic exporter or regular exporter (Ural and Acaravci, 2006). The diversification of export market, in fact, influences regular export activity and it is relevant to consider different levels of presence regularity in the different markets. E-learning and maintenance at distance facilitated by Industry 4.0 (Del Giudice et al., 2019) might allow a greater development of customer relationships over time. Valaskova et al. (2022) show that opportunities coming from Industry 4.0 adoption may increase future export improving

customer relationships. Moreover, as highlighted by Kafouros et al. (2008) and Zahra and Covin (1995) Industry 4.0 might help firms in facing changes in highly competitive global market. This also might facilitate export regularity in changing scenarios. Hence, the following hypothesis is posed:

HP2 – SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have a higher degree of export regularity in a given period.

The third export dimension identified in the literature is the newness of exporting status, referring to the fact that non-exporting SMEs start to export in a certain period of time. This aspect is related to the fact that, to increase their sales, firms need to find new markets (Dunning, 1998). Literature highlights that the decision to enter a new market is not an easy one for SMEs. Exporters face various entry costs associated with acquiring information about foreign buyers, developing communication of their offer, and researching the characteristics of the foreign market and its regulatory environment. Studies on Industry 4.0 point out that 4.0 technologies can facilitate this process through the acquisition and analysis of large masses of data even at a distance and through the possibility of reducing international information and marketing barriers (Hosseini et al., 2019). In addition, Industry 4.0 enables to globally expand the exchange of data on customers' preferences (Castagnoli et al., 2022). Therefore, the following hypothesis is stated:

HP3 – SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have a newness of exporting status in a given period.

The fourth export dimension is the export intensity, measuring the share of export turnover on total turnover (Haddoud et al., 2021, Hagsten and Kotnik, 2017). Literature highlights that Industry 4.0 might facilitates simultaneous presence in several markets (Ahokangas et al., 2014) and management of global distribution of products (Szalavetz, 2019). Tvaronaviciene and Burinskas (2020) show that Industry 4.0 allows firms to be more efficient and that more

efficient firms sell more high-quality products in more markets (Wichitsathian and Nakruang, 2019), having a positive impact on export intensity.

Literature on Industry 4.0 highlights that 4.0 technologies not only affect the decision to export, but also the export intensity (Hagsten and Kotnik, 2017) through labor productivity (this causal relationship usually takes into account the increase in labor productivity that in this study is not taken into account). Therefore, the following hypothesis is formulated:

HP4 – SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have a higher export intensity at a given time.

The fifth export dimension is the export growth, considering whether the firm augment or not export in the considered period (Bodlaj et al., 2020) and corresponds to a relative change in firms' export intensity over time (Bodlaj et al., 2020). Wagner (2015) stresses the importance of learning by exporting, where knowledge flows from buyers and exposure to international competition helps firms to improve their post-entry performance. Bodlaj et al. (2020) states that organizational and product innovations affect export growth, and that this is more relevant in geographically dispersed markets. In this direction, Industry 4.0 enables better acquisition of information on foreign markets (Manyika et al., 2015; Strange and Zucchella, 2017; Merchant, 2018), which may generate increased sales in foreign markets. Moreover, following Nosirov et al. (2023), Industry 4.0 also increases export activity of high-tech firms, by increasing quality of engineering and operational dimension, such as reducing errors and lead times and delivering larger orders. Following this assumption, it is useful to understand if this result is valid also for manufacturing SMEs, positively impacting on export growth. Therefore, the following hypothesis is posed:

HP5 – SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have experienced an export growth.

Moreover, literature identifies variables on factors that may influence SMEs' propensity to 4.0 transformation and export, such as: demographic aspects; localization; market orientation; innovation propensity; human capital.

Ganotakis and Love (2012) explores SMEs export through the theoretical lenses of human capital theory (Haddoud et al., 2021). Human capital is a potential critical factor affecting the export behaviour of SMEs (Rundh, 2011; Ruzzier and Ruzzier, 2015; Reuber and Fischer, 1997). More specifically, a high level of skills could favor the foreign markets entry as well as the link between exporting and innovation (Love and Mansury, 2009).

Furthermore, the market orientation (Pyper et al., 2019) may vary depending on whether firms operate for the final market (B2C) or for subcontracting (B2B).

Export literature also points out that age and size are firms' characteristics potentially influencing the export behavior (e.g. Wagner, 2015; Ruzzier and Ruzzier, 2015).

Rodríguez and Rodríguez (2005) empirically underline that technology intensive industries may affect firms' export behavior.

According to the literature, firms generally perform better when they face a benign domestic environment since the location advantage – which includes knowledge-based assets, infrastructure and technology (Stentoft et al., 2021) – shapes firms' competitiveness (Dunning, 1998). In particular, in Italy there are wide geographical differences in terms of endowment and quality of infrastructure and economic development level (D'Onofrio et al., 2019).

The export literature highlights that the outcomes of export activities can differ by country of destination (Haddoud et al., 2021). In particular, a distinction is made between emerging countries, non-European OECD countries, and countries within the EU. The latter is related to the fact that the European market can facilitate the transition of goods between countries by eliminating customs barriers.

In light of the theoretical background presented, the following conceptual framework can be identified (Figure 1).

"Figure 1 about here"

3. Materials and methods

3.1 Data

The main data source is a database related to a survey on manufacturing firms carried out by Unioncamere (Italian Union of Chambers of Commerce) in 2022 on a representative sample of almost 2,972 Italian manufacturing SMEs (Unioncamere, 2022), corresponding to 2.3% of the universe of Italian population in terms of firms and 4.8% in terms of employees. The stratification considers three dimensions of firms: i) industry (24 divisions of the section C manufacturing sector of the Nace Rev.2 classification); ii) size class in terms of employees (5-9, 10-19, 20-49, 50-249); iii) geographical location (North-West, North-East, Center, South). The maximum sampling error is small (e=1.8%; α=0.95%). The survey is carried out by Computer-Assisted Telephone Interviewing method by a professional contractor, with the aim of gathering both qualitative and quantitative information on the firms. Several preliminary briefings are held with the contractor aiming to explain to interviewees the exact meaning of the questions, with particular reference to those concerning Industry 4.0. The quality of the data is subsequently validated. Furthermore, according to Dorling and Simpson (1999), the quality of data is also ensured by the fact that they come from a public agency, confirming a high response rate and the representativeness of the population.

This is an encouraging trend for the generalizability of findings, since, as shown in the study by Haddoud et al. (2020), the samples generally used in SMEs' export analyses are numerically smaller. In fact, about 58% have samples lower than 500 firms, about 14% from 500 up to 1000 SMEs and about 27% of studies more than 1000 firms.

The surveys contain two specific sections on Industry 4.0 and on export. They also contain other information about market orientation (B2C/B2C), education level of the workforce, economic performance. Information about some firms' characteristics (e.g. age, economic sector) comes from administrative archives. The data on firms' export includes information about firms' exporter status (exporter/non exporter) in the years prior to 2022, according to administrative archives. In detail, through the merge between administrative data and those coming from the survey, the research constructs a cross section exploring different export dimensions in: 2022, concerning exporting status and export intensity; 2021 and 2022, concerning export growth; the period 2017-2022 concerning export regularity; 2021-2022 compared to the period 2017-2020.

3.2. Variables description

The analysis considers 5 dependent variables, 1 independent variable and 10 control variables as reported in Table 2.

"Table 2 about here"

3.3 The method

The research investigates the effects of Industry 4.0 on different export dimensions. Several models are used depending on the type of dependent variable (exporting status, export regularity, newness of exporting status, export intensity, export growth): Probit (e.g. Wooldridge, 2010, pp. 453-459), Tobit (Tobin, 1958, recently Greene, 2018 pp. 973-977) and Ordered Probit (Zavoina and McElvey, 1975; recently Greene, 2018, p. 909-913), see Table 3.

"Table 3 about here"

The regression structure is the following.

$$Y_i = \beta_0 + \beta_1 I40_i + \beta_2 C_i + \varepsilon_i \qquad \varepsilon_i \sim N(0,\sigma^2)$$

Where:

- Y_i is the dependent variable measuring the export according to the various types of indicators.
- I40 is the independent variable measuring Industry 4.0. In line with previous studies (Azar and Ciabuschi, 2017; Dalenogare et al., 2018), Industry 4.0 is measured as adoption of more than one 4.0 technologies usually adopted in a phased manner (Frank et al., 2019). To measure Industry 4.0, it is used a variable on a scale 0-12 according to the number of 4.0 technologies adopted by the firm (I40). The variable is coded as zero to indicate the case in which no technologies are implemented and is coded as twelve if all the technologies are implemented. The 12 technologies come from the classification by Rüßmann et al. (2015) –robotics, augmented reality, internet of things, big data, cloud computing, cyber security, additive manufacturing, simulation, horizontal and vertical integration – and the emerging technologies of blockchain (Purwaningsih et al., 2024), machine learning (Shetewy et al., 2022), and artificial intelligence (Brynjolfsson et al. 2019).
- C_i is a vector including the control variables capturing firms' characteristics that may influence SMEs' propensity to 4.0 transformation and export: demographic aspects (SIZE and AGE); localization (NORTH-WEST, NORTH-EAST, CENTER AND SOUTH); market orientation (B2B, B2C, EXP_EU); innovation propensity (HIGH-TECH); human capital (HUMAN_CAPITAL). With specific regard to analyses on exporting firms, focusing on export performances (export intensity, export growth – Ayoub and Abdallah, 2019; Al-Ghwayeen, et al., 2018) the econometric models also control for the condition that the firm is only exporter in UE countries, since the absence of barriers in the European market potentially may affect the export performances (see Table 2).
- ε_i is the normally distributed random error with zero mean and constant variance N $(0, \sigma^2)$ that captures any other unknown factor.

The analysis calculates the marginal effects at the means – MEMs – (Cameron and Trivedi, 2010; Williams, 2012) after Probit and Ordered Probit regressions to measure the impacts of the explanatory variables on:

i) the probability of success (Y=1) for binary response variable (exporting status, newness of exporting status, export growth);

ii) the probability of being in each category (Y=0, Y=1, Y=2) for the ordered response variable (export regularity).

For all the regressions the analysis calculates robust standard error to control for heteroskedasticity. The analyses are carried out on: exporting status and export intensity in a cross-section data coming from the survey of 2022; export growth in a cross section data in 2021 and 2022; export regularity in the cross section in the period 2017-2022; and newness of exporting status in the cross section of the period 2021-2022 compared to the period 2017-2020. Stata version 15 is used for all the estimates.

The decision to use the regression method is supported by the fact that, as highlighted in the systematic literature review by Haddoud et al. (2021), more than 60% of studies on exports and SMEs are carried out by regressions.

4. Results

4.1 Descriptive analysis results

Table 4 reports summary measures of the dependent, independent and control variables considered for the analyses, reporting their number of observations (Obs), percentage values (%), mean (Mean), standard deviation (Std. Dev.) and minimum (Min) and maximum (Max) values. The sample analyzed includes a total of 2,972 Italian manufacturing SMEs. The paper verifies that 53% of the sample of 2,972 manufacturing Italian SMEs exports in 2021-2022 (table 4).

Looking at export regularity, more than one third of the firms (38.9%) are regular exporters (namely exporters in all years of the period 2017-2022), and around one-fifth are not regular exporter (26.6%), beside those non exporters (34.5%). According to the newness of exporting status, 10.3% of firms are new exporters in the biennium 2021-2022 (namely non exporters in any years from 2017 to 2020 and exporters in 2021-2022).

In the sub-set of exporting SMEs, the export share on total sales (export intensity) is 39.5% and 22.3% registered an increase in export in two consecutive years, both in the year of the survey (2022) and in the previous year (2021 – export growth).

The 26.6% of the sample of 2,972 manufacturing Italian SMEs adopts 4.0 technologies with a mean of 2.9 4.0 technologies adopted (among SMEs adopting Industry 4.0) on a scale 1-12.

The sample has the following characteristics: 9.7% are graduated employees; 65.9% operates for the final market and 34.1% for subcontracting; the average firm age is 32 years old; 18.5% belongs to the high/medium-high intensive technology industries; 31.7% is located in the North-West, 31.5% in the North-East, 20.2% in the Center and 16.6% in the South.

"Table 4 about here"

Figure 2 shows that the most adopted technologies are simulation (41.1%), big data (40.5%), and advanced manufacturing (38.9), while the less implemented one is blockchain (5.9%).

"Figure 2 about here"

Table 5 presents the correlation matrix. Collinearity problem does not emerge, as shown in table 5, since correlation coefficients are all below the critical value of 0.7 (Tabachnick and Fidell, 1996).

"Table 5 about here"

4.2 Confirmatory analysis results

The results of the regression models are summarized, for each hypothesis, in a table reporting the independent variable (Industry 4.0), the dependent variable (exporting status, export

regularity, newness of exporting status, export intensity and export growth) and the control variables on factors that may influence SMEs' propensity to 4.0 transformation and export (variables related to demographic aspects, location, market orientation, innovation propensity, human capital).

The results report the Wald test Chi Square for Probit and Ordered Probit regressions, and F-statistic for Tobit regression: the p-value is < 0.01 for all models, rejecting the null hypothesis that all of the regression coefficients are simultaneously equal to zero.

Each table presents model, marginal effect (ME), p-value, robust standard errors (Rse). The five models confirm HPs as they report statistically significant coefficients for Industry 4.0 with the control variables.

Table 6 shows the effects of Industry 4.0 on exporting status, verifying HP1 which proposes that SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have a positive exporting status at the same given time. The results show that: ME=0.033; p-value<0.01; Rse=0.007. Therefore, HP1 is accepted.

"Table 6 about here"

Table 7 reports the effects of Industry 4.0 on export regularity distinguished in not exporter, sporadic exporter and regular exporter. HP2 states that SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have higher degree of export regularity in a given period. The results verify that: ME=0.029; p-value<0.01; Rse=0.006. Hence, HP2 is accepted.

"Table 7 about here"

Table 8 summarizes the effects of Industry 4.0 on newness of exporting status, verifying HP3, which affirms that SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have a newness of exporting status in a given period. The results show that: ME=0.007; p-value<0.01; Rse=0.003. Consequently, HP3 is accepted.

"Table 8 about here"

Table 9 focuses on the effects of Industry 4.0 on export intensity. This points out the results of HP4, highlighting that SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have a higher export intensity at a given time: ME=1.339; p-value<0.01; Rse=0.285. Accordingly, HP4 is accepted.

"Table 9 about here"

Table 10, finally, describes the effects of Industry 4.0 on export growth. This makes evident the results for HP5, stating that SMEs adopting a higher number of 4.0 technologies at a given time are more likely to have experienced an export growth at a given time: ME=0.019; p-value<0.01; Rse=0.005. Thus, HP5 is accepted.

"Table 10 about here"

5. Discussion

The results of the study contribute to the literature on the effects of Industry 4.0 on SMEs' export by quantitatively verifying that Industry 4.0 – measured as increasing (Azar and Ciabuschi, 2017) adoption of one or more technologies – has a positive impact on different export dimensions (Naglič et al., 2020; Valaskova et al., 2022).

The sample is carried out on more recent and larger data in comparison with most existing studies in the literature on export (Haddoud et al., 2021). The 58% of existing studies adopt samples with less than 500 SMEs. The sample also shows – in line with other studies on the topic (Naglič et al., 2020) – a high level of export, since 53% of the analyzed SMEs exports. This result, however, leaves wide margin for the improvement in increasing SME exports beyond 53% of SME and consequently suggests the need and relevance to identify drivers for increasing it, such as Industry 4.0 (Azar and Ciabuschi, 2017; Naglič et al., 2020; Valaskova et al., 2022).

The results show a technological adoption of 26.6% (< 25% of the German adoption rate – Rüßmann et al., 2015) with a mean number of technologies adopted of 2,9. This difference is explained by the delay of the industrial plan Piano Nazionale Industria 4.0 (Minister of Economic Development of Italy, 2016) compared to the German industrial plan Industrie 4.0, launched in 2011 (Kagermann et al., 2013). Moreover, firms in Italy are in the majority SMEs, while in Germany there are more big players, directing and guiding SMEs in the transition to Industry 4.0 (Kagermann et al., 2013). The result on the low number of technologies adopted in the sample (around 2.9 in mean on a scale from 0 to 12, with simulation – 41.1%), big data (40.5%), and advanced manufacturing (38.9) as most adopted technologies), however, doesn't allow a blatant empirical verification of the literature's assumption that an increasing number of 4.0 technologies adopted might lead to an increasing export in SMEs (Azar and Ciabuschi, 2017). This result might become more evident in future – also through the use of public incentives in support of 4.0 technological adoption – leading to a clearer verification of the literature on the positive effect of an increasing and phased adoption of 4.0 technologies on export.

The study deepens the analysis by verifying the effects of Industry 4.0 on five export dimensions.

The positive effect of Industry 4.0 on exporting status may depend by the strong relationship between firms' propensity to innovate in Industry 4.0 and exporting status (Sarbu, 2022), and to improve competitiveness and attractiveness on global markets through a reduction in workforce costs (Erer and Erer, 2020). This finding expands the literature on the effects of individual 4.0 technologies (Hannibal, 2020) on export to the concept of a combination of more 4.0 technologies. This result empowers previous analysis through a quantitative rather than conceptual study (Erer and Erer, 2020; Hannibal, 2020), focusing on Italy rather than on Germany (Sarbu, 2022).

The positive effect of Industry 4.0 on export regularity confirms literature on international supply chain management (Porter and Heppelman, 2014; Strange and Zucchella, 2017), e-learning and maintenance at distance (Del Giudice et al., 2019), and greater relationships with customers over time (Castagnoli et al., 2020; Valaskova et al., 2022). This result strengthens previous analyses by: carrying out a quantitative rather than a conceptual (Porter and Heppelman, 2014; Strange and Zucchella, 2017) or qualitative (Castagnoli et al., 2020) analysis; studying a higher number of technologies, rather than only X-reality (Del Giudice et al., 2019) or big data, internet of things, additive manufacturing and robotics (Strange and Zucchella, 2017); verifying the relationship on a bigger sample, 2,972 SMEs rather than 4 firms Valaskova et al., 2022).

The positive effect of Industry 4.0 on newness of exporting status is in line with literature on SMEs liabilities in obtaining foreign market information and reaffirms the literature on the ability of Industry 4.0 to reduce international information and marketing barriers (Hosseini et al., 2019) and to obtain global customer's preferences (Castagnoli et al., 2022). This result extends existing studies (Hosseini et al., 2019): investigating a different country, Italy rather than Iran and Turkey; testing on a bigger sample, 2,972 rather than 622 SMEs, and analyzing more technologies rather than only cloud computing.

The positive effect of Industry 4.0 on export intensity confirms literature on export and advanced technologies (Hagsten and Kotnik, 2017) enrishing literature by testing that the positive relationship between ICT and export intensity is also true for Industry 4.0, bridging the research gap on Industry 4.0 and export intensity.

The positive effect of Industry 4.0 on export growth confirms the literature on the ability of Industry 4.0 to: enable better information acquisition in foreign markets (Manyika et al., 2015; Strange and Zucchella, 2017; Merchant, 2018); offer products created on customer needs and facilitate international supply and distribution networks (Ahokangas et al., 2014);

increasing quality of engineering, reducing errors and delivering larger orders (Nosirov et al., 2023). This result extends the existing analyses by focusing on more technologies rather than only on, for example, internet of things (Manyika et al., 2015) or cloud computing (Ahokangas et al., 2014).

The positive impacts of Industry 4.0 on the five export dimensions, may depend on the fact that Industry 4.0, requiring high initial investments, might push firms to expand the scale of production, increasing production for foreign markets (Büchi et al., 2018) and therefore increasing export. However, the results also show a stronger effect on export intensity and export regularity and a fewer one on newness of exporting status. Hence, Industry 4.0 mainly affects SMEs already working for export increasing their impact on international markets, while SMEs approaching for the first time to export has issues in absorbing simultaneously new technologies and information on new international markets. This is also in line with literature pointing out the role of a phased and gradually increasing adoption of 4.0 technologies to obtain greater opportunities (Frank et al., 2019). Adopting new technologies, in fact, and at the same time new approach on international markets require investments costs and time to change strategic and operational management of the firms that might temporarily undermine the positive effects of Industry 4.0.

Therefore, answering to the main questions posed in the introduction of the study, it is possible to state the following propositions. SMEs, characterized by foreign and smallness liabilities, may be facilitated by Industry 4.0 in global market integration through different export dimension, but in particular through export intensity and export regularity. By contrast, newness of exporting status is the fewer affected dimension due to the time required for innovation absorption (Stachowiak et al., 2019). Moreover, the role of Industry 4.0 as a factor affecting SMEs' entry to export markets mainly depend by an increasing adoption of more 4.0 technologies implemented in a phased manner.

6. Conclusion

The paper verifies the effects of Industry 4.0 on five export dimensions – exporting status, export regularity, newness of exporting status, export intensity and export growth – through a quantitative analysis on a statistically representative sample of large and fresh data of 2,972 Italian manufacturing SMEs.

The paper theoretically contributes to existing literature in three ways.

First, the study, conceptualize and operationalize the concept of Industry 4.0, export dimensions and factors that may influence SMEs' propensity to 4.0 transformation and export.

Second, the paper goes beyond existing studies in three key points.

- Analyzing the effects of single 4.0 technologies or digital reorganization (Naglič et al., 2020) by considering a higher number of 4.0 technologies.
- Extending the existing quantitative analysis from a geographical perspective, investigating Italian SMEs rather than Slovak (Valaskova et al., 2022) and Slovenian firms (Naglič et al., 2020).
- Expanding the size of quantitative sample from 4 (Valaskova et al., 2022) and 81 (Naglič et al., 2020) firms, to 2,972 SMEs.
- Enriching the industries analyzed by studying manufacturing SMEs rather than only automotive (Valaskova et al., 2022) or processing industry (Naglič et al., 2020).

Third, the results verify the effects of Industry 4.0 on five export dimensions.

The originality of the study is twofold. First, it shows that Industry 4.0, highly based on digitalization, goes further improving through strategic and operational changes the impact on different SMEs' export dimensions not analyzed by the existing literature. Second, it lies in empirically verifying that Industry 4.0 enables not only to achieve the exporting status, but

also faster, more regular, broader and growing export.

From a practical perspective, the study has two main implications.

First, the research suggests that entrepreneurs should adopt more 4.0 technologies in SMEs to achieve higher export levels, and shows how firms and policy makers should jointly consider strategies for technological innovation and foreign expansion (Rauf et al., 2021). Industry 4.0, in fact, allows for both greater efficiency and effectiveness in production and at the same time positive impacts on global markets, allowing for a better payback on the initial investment.

Second, the work encourages SMEs to enter export markets (Mansion and Bausch, 2020) without heavy need for government intervention traditionally given to support SMEs export (Haddoud et al., 2017). This may suggest that policy makers might make a choice between incentivizing more innovation policies rather than internationalization policies because of their dual positive impact on SMEs.

However, as pointed out in the empirical study by Ghobakhloo et al. (2023), the success of Industry 4.0 design and related integration, virtualization, real-time automation, and servitization capabilities is resource-dependent. Hence, it requires significant upfront investment and continuous resource allocation. These activities turn out to be particularly costly from both an economic and organizational point of view in terms of adoption of technologies, acquisition of new skills and reorganization of the business (Büchi et al., 2018). Therefore, there is the need to evaluate it in light of the possible export opportunities arising from this transformation. Moreover, this implies the need to evaluate in investment choices the impacts not only in terms of effectiveness and efficiency of technological performance but also in terms of export.

The results suggest the need of further studies considering control variables as moderators, namely: skilled workforce, B2B or B2C market, age, size, sector and geographical area on the dependent variables, on the independent variables or on the effect of Industry 4.0 on export

dimensions. Moreover, a cross-countries analysis might be carried out considering also differences between developed and emerging countries. Finally, the potential role of other factors affecting Industry 4.0 adoption and export should be considered. These factors may be internal ones (availability of economic-financial resources, digital competences of human-resources, firms' organization model) or external ones (economic infrastructures, innovation intermediaries enabling SMEs' growth).

Declaration of interest statement

The views expressed in the article are those of the authors and not of the institution they are affiliated with.

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Tables

Table 1. Impact of 4.0 on export strategies

4.0 technology	Impact on export strategies	Authors (year)
Additive manufacturing	- enabling response to technological and environmental changes in highly competitive global markets	Kafouros et al. (2008); Zahra and Covin (1995)
Advanced manufacturing	- enabling response to technological and environmental changes in highly competitive global markets -facilitating to enter export markets and improve export performance reducing variable production costs -facilitating to win export competition and increase market share -fiercer market competition when improving the productivity of firms	Kafouros et al. (2008); Zahra and Covin (1995) Zhang et al. (2023)
Big data	-change in export strategies through high-speed connectivity -monitoring emerging trends and opportunities in overseas markets -optimize supply, production, and distribution activities around the world	Strange and Zucchella (2017)

	-facilitating business activities expansions to international, fast growing and distant ones markets -increasing export performance	AL-Khatib (2023)
Artificial intelligence	- improving export product quality by boosting resource allocation efficiency and information-processing abilities	Xu and Tian (2023)
	-facilitating exports allowing a substantial reduction in translation costs and helping to face language barriers	Brynjolfsson et al. (2019)
Blockchain	-increasing export performance and fostering international trade success	Purwaningsih et al. (2024)
Cloud computing	- increasing export performance indicators, such as export value, export intensity and export in most dynamics sectors	Boccia et al. (2022)

Source: own elaboration

Table 2. Variables description

Variables	Description
Dependent variable	
EXP_STATUS	Dummy: 1 if the firm exports in 2021-2022
EXP_REGULARITY	Categorical: 0 if the firm do not export over the entire period 2017-22; 1 if the firm is a sporadic exporter (exporter in not every year over the period 2017-22); 2 if the firm is a regular exporter (exporter in all years of the period 2017-22)
EXP_NEW	Dummy: 1 if the firm do not export over the period 2017-2020 and exports in 2021-2022
EXP_INTENSITY	Continuous censored: share of foreign sales on total sales
EXP_GROWTH	Dummy: 1 if the firm registers an increase in export both in 2022 and in 2021
Independent variable	
I40	Discrete (0-12): number of technologies 4.0 adopted by the firm (robotics, augmented reality, internet of things, big data, cloud computing, cyber security, additive manufacturing, simulation, horizontal and vertical integration, blockchain, machine learning, artificial intelligence)
Control variables	
HUMAN_CAPITAL	The share of graduated employees
B2C	Dummy: 1 if the firm operates for the final market
B2B	Dummy: 1 if the firm operates for subcontracting
AGE	Number of years since inception
SIZE	Number of employees
HIGH-TECH	Dummy: 1 if the firm belongs to high- medium-high -technology intensive industry (following the EUROSTAT classification of manufacturing industries by technological openness).
NORT-WEST	Dummy: 1 if the firm is located in the North-West
NORTH-EAST	Dummy: 1 if the firm is located in the North-East
CENTER	Dummy: 1 if the firm is located in the Center

SOUTH	Dummy: 1 if the firm is located in the South
EXP_UE	Dummy: 1 if the firm exports only in EU countries

Source: own elaboration

Table 3. Summary methods

Dependent variable (Y_i)	**Values of the dependent variable**	**Typology**	**Model**	**Type of analysis**	**Table of results**
Exporting status (EXP_STATUS)	1= exporter in 2021-2022 (regardless the previous year) = 0 otherwise	Binary	Probit	Cross section	Tab. 6
Export regularity (EXP_REGULARITY)	0 = not exporting (in the period 2017-2022) 1 = sporadic exporter (in the period 2017-2022); 2 = regular exporter (in the period 2017-2022)	Ordered	Ordered Probit	Cross section	Tab. 7
Newness of exporting status (EXP_NEW)	1= new exporter in 2021-2022 and not exporter in the period 2017-2020 = 0 otherwise	Binary	Probit	Cross section	Tab. 8
Export intensity (EXP_ INTENSITY)	1-100	Continuous censored	Tobit	Cross section	Tab.9
Export growth (EXP_GROWTH)	1 = export growth (in the period 2021-2022) 0 = otherwise	Binary	Probit	Cross section	Tab.10

Source: own elaboration.

Table 4. Summary statistics

	Obs	%
EXP_STATUS	2,972	53.0
EXP_REGULARITY=0	2,972	34.5
EXP_REGULARITY=1	2,972	26.6
EXP_REGULARITY=2	2,972	38.9
EXP_NEW	2,972	10.3
EXP_GROWTH[a]	1,576	22.3
B2C	2,972	65.9
B2B	2,972	34.1
HIGH-TECH	2,972	18.5
NORT-WEST	2,972	31.7
NORTH-EAST	2,972	31.5
CENTER	2,972	20.2
SOUTH	2,972	16.6
EXP_UE	2,972	4.6

	Obs	Mean	Std. Dev.	Min	Max
EXP_INTENSITY[a]	1,576	39.455	29.299	1	100
I40[b]	1,218	2.862	.837	1	12
HUMAN_CAPITAL	2,972	9.721	14.719	0	100
AGE	2,972	32.086	16.467	3	135
SIZE	2,972	33,428	43.958	5	247

[a] On the total of exporting firms in 2021-2022.

[b] On the total of firms adopting technologies 4.0.

Source: own elaboration

Table 5. Correlation matrix

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. I40	1.000								
2. HUMAN_CAPITAL	0.224	1,000							
3. B2B	0.103	-0.033	1,000						
4. AGE	0.069	0.021	0.038	1,000					
5. SIZE	0.341	0.232	0.037	0.185	1,000				
6. HIGH-TECH	0.088	0.170	-0.083	0.032	0.126	1,000			
7. NORTH-WEST	0.017	-0.014	0.082	0.171	0.042	0.080	1,000		
8. NORTH-EAST	0.002	-0.006	-0.020	0.025	0.010	0,056	-0.462	1,000	
9. CENTER	-0.036	-0.000	-0.013	-0.100	-0.056	-0.064	-0.342	-0.341	1,000
VIF	1.18	1.11	1.03	1.08	1.21	1.07	2.11	2.04	1.78

Source: own elaboration

Table 6. Results: Industry 4.0 and the exporting status: marginal effects of Probit regression (total sample)

	EXP_STATUS
I40	0.033***
	(0.007)
HUMAN_CAPITAL	0.008***
	(0.001)
B2B	0.022
	(0.021)
AGE	0.001
	(0.001)
SIZE	0.003***
	(0.000)
HIGH-TECH	0.154***
	(0.027)
NORTH-WEST	0.103***
	(0.030)
NORTH-EAST	0.039
	(0.030)
CENTER	0.032
	(0.033)
Observations	2,972
Pseudo R^2	0.159
Wald Chi-square	244.00***

The dependent variable is at the top the column. Table displays marginal effects at the means (MEMs) of the Probit regression. Robust standard errors in parentheses. Reference category is: B2C for the market orientation; SOUTH for geographical location.

*** p < 0.01, ** p < 0.05, * p < 0.1.

Source: own elaboration

Table 7. Results: Industry 4.0 and the export regularity: Ordered Probit regression (total sample)

	Ordered Probit	Marginal effects at the means		
		EXP_REGULARITY=0 (Not exporter)	EXP_REGULARITY=1 (Sporadic exporter)	EXP_REGULARITY=1 (Regular exporter)
	(A)	(B)	(C)	(D)
I40	0.076***	-0.026***	-0.003***	0.029***
	(0.014)	(0.005)	(0.001)	(0.006)
HUMAN_CAPITAL	0.019***	-0.006***	-0.001***	0.007***
	(0.002)	(0.001)	(0.000)	(0.001)
B2B	0.065	-0.022	-0.003	0.025
	(0.047)	(0.016)	(0.002)	(0.018)
AGE	0.004***	-0.002***	-0.000***	0.002***
	(0.001)	(0.000)	(0.000)	(0.001)
SIZE	0.008***	-0.003***	-0.000***	0.003***
	(0.001)	(0.000)	(0.000)	(0.000)
HIGH-TECH	0.453***	-0.153***	-0.021***	0.174***
	(0.062)	(0.021)	(0.005)	(0.024)
NORTH-WEST	0.372***	-0.128***	-0.013***	0.140***
	(0.069)	(0.024)	(0.004)	(0.025)
NORTH-EAST	0.222***	-0.079***	-0.002	0.082***
	(0.066)	(0.024)	(0.002)	(0.024)
CENTER	0.184**	-0.066**	-0.000	0.067**
	(0.074)	(0.027)	(0.002)	(0.027)
Observations	2,972	2,972	2,972	2,972

Pseudo R^2	0.154
Wald Chi-square	406.53***

The dependent variable is at the top the column. Table displays marginal effects at the means (MEMs) of the ordered Probit regression. Robust standard errors in parentheses. Reference category is: B2C for the market orientation; SOUTH for geographical location.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: own elaboration

Table 8. Results: Industry 4.0 and the newness of exporting status: marginal effects of Probit regression (total sample)

	EXP_NEW
I40	0.007**
	(0.003)
HUMAN_CAPITAL	0.001***
	(0.000)
B2B	0.014
	(0.011)
AGE	-0.000
	(0.000)
SIZE	-0.002***
	(0.000)
HIGH-TECH	-0.019
	(0.015)
NORTH-WEST	-0.030*
	(0.018)
NORTH-EAST	-0.035**
	(0.017)
CENTER	0.038**
	(0.018)
Observations	2,873
Pseudo R^2	0.051
Wald Chi-square	45.19***

The dependent variable is at The top the column. Table displays marginal effects at the means (MEMs) of the Probit regression. Robust standard errors in parentheses. Reference category is: B2C for the market orientation; SOUTH for geographical location.

*** p < 0.01, ** p < 0.05, * p < 0.1.

Source: own elaboration

Table 9. Industry 4.0 and export intensity: Tobit regression (subsample of exporting firms in 2021-2022)

	EXP_INTENSITY
I40	1.339***
	(0.285)
HUMAN_CAPITAL	0.169***
	(0.047)
B2B	-5.197***
	(1.438)
AGE	-0.100**
	(0.043)
SIZE	0.087***
	(0.008)
HIGH-TECH	11.377***
	(1.681)
NORTH-WEST	7.660***
	(2.125)
NORTH-EAST	5.509**
	(2.161)
CENTER	11.341***
	(2.403)
EXP_UE	4.107*
	(2.741)
Constant	24.473***
	(2.283)
Observations	1,576
Pseudo R^2	0.018

F-statistics	41.17***

The dependent variable is at the top the column. Robust standard errors in parentheses. Tobit regression: lower limit =1; upper limit =100. Reference category is: B2C for the market orientation; SOUTH for geographical location.

*** p < 0.01, ** p < 0.05, * p < 0.1.

Source: own elaboration

Table 10. Industry 4.0 and export growth: marginal effects of Probit regression (subsample of exporting firms in 2021-2022)

	EXP_GROWTH
I40	0.019***
	(0.005)
HUMAN_CAPITAL	-0.000
	(0.001)
B2B	-0.021
	(0.022)
AGE	0.000
	(0.001)
SIZE	0.001***
	(0.000)
HIGH-TECH	0.009
	(0.025)
NORTH-WEST	0.022
	(0.031)
NORTH-EAST	0.045
	(0.032)
CENTER	0.060*
	(0.036)
EXP_UE	0.042
	(0.038)
Observations	1,576
R-squared	0.033
Wald Chi-square	56.75***

The dependent variable is at the top the column. Table displays marginal effects at the means (MEMs) of the Probit regression. Robust standard errors in parentheses.

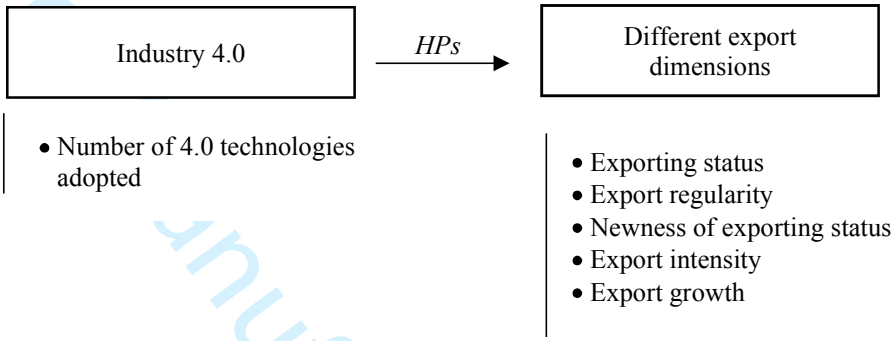
Reference category is: B2C for the market orientation; SOUTH for geographical location.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: own elaboration

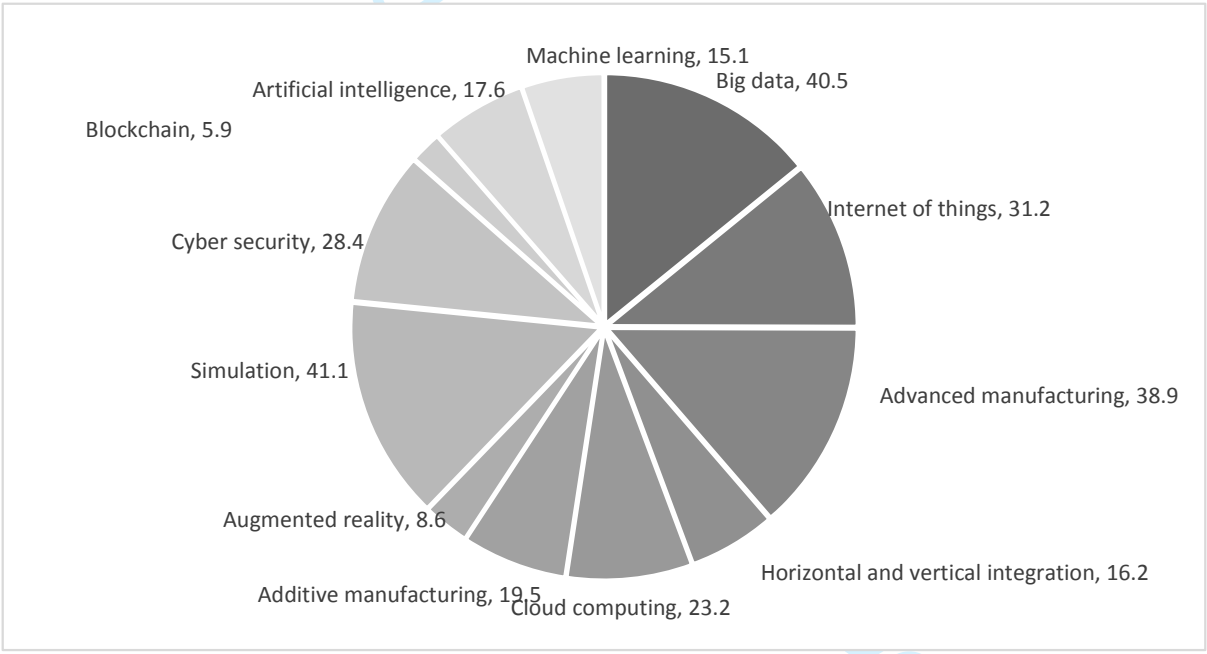
Figures

Figure 1. Development of conceptual framework



Source: own elaboration

Figure 2. 4.0 technologies adopted



n. SMEs 4.0 218; Tot. technologies 3.486

Source: own elaboration

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