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Industry 4.0 and Digital Innovation in Manufacturing: State of the Art Technology and Future Prospects in the Italian Mechanical Engineering Sector

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Abstract

The label 'Industry 4.0' has captured increasing attention in recent years. However, despite impressive media coverage, EU activism, and being featured in many government programs, the picture of the actual diffusion and realistic industrial potential of the so-called 'Industry 4.0 enabling technologies' is still unclear. Far from filling this gap at the European or global level, in this paper we focus one specific, though relevant, industrial domain: the Italian mechanical engineering sector. The analysis shows the magnitude of a phenomenon that has undoubtedly been subject to some excessive rhetoric. Nevertheless, our findings show that things are progressing as the early adopters (mostly large businesses) are beginning to invest in and develop strategic plans for future action. However, most players such as small-sized family-owned enterprises are simply looking at the moment, and do not appear to have a strategy in approaching Industry 4.0 or any plan for getting on board in the near future, and this is something industrial and political leaders should take note.

1. Introduction

The label 'Industry 4.0' has captured increasing attention in recent years, both in the business world and among policy makers. Although there is currently no official classification of Industry 4.0, researchers and practitioners, as well as journalists and government experts, are getting used to adopting this label as an umbrella term for many recent technology-based innovations in manufacturing, such as the integration of 'cyber-physical systems' into factory processes (Evans and Annunziata, 2012; Almada-Lobo, 2015).

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Roadmap guidelines for both factories and governments usually focus on the adoption of selected 'enabling technologies' such as additive manufacturing, the internet of things, big data analytics, collaborative robots, augmented reality, and cloud computing (Hermann *et al*., 2015; Metzger, 2016; Smit *et al*., 2016). However, there are other technologies also associated with Industry 4.0, such as power supply, materials technology (e.g., nanotechnologies), microelectronics, data processing, digital fabrication (e.g., CAD/CAM), cognitive technologies (artificial intelligence, machine learning, etc.), automation, communication, cyber-security tools, and so on (Garibbo and Arricchiello, 2018). 'Smart factories', 'Smart industry', 'Advanced manufacturing', or 'Industrial Internet' are all terms related to Industry 4.0 and are sometimes used as synonyms.

The EU has a vital role in this process. The Horizon 2020 program 'Manufuture' defined a strategic objective for the Union to significantly increase the manufacturing industry's share in the economy, along with adopting a decisive stance for the integration of new technologies and innovations.

In addition to the German program 'Industrie 4.0' (Kagermann *et al*., 2013), which served as the foundation for all future policy development in relation to Industry 4.0, there are a considerable number of current national action plans aimed at revitalising manufacturing activities including the Revitalize American Manufacturing and Innovation Act (USA), Industrie du future (France), High Value Manufacturing (United Kingdom), Make in India (India), Industrial Value Chain Initiative (Japan), and Piano Nazionale Industria 4.0 (Italy).

With the EU and the US still suffering from the aftermath of the economic crisis, it is no wonder that the promise of a 'fourth industrial revolution' (Schwab, 2017; Bloem *et al*., 2014) is receiving greater attention. However, in order to move from words to action, there should first be a more detailed picture of both the actual adoption of these technologies at the sector level and entrepreneurs' willingness to invest.

Far from filling this gap at the European or global level, in this paper we aim to provide a reliable picture of the adoption of state-of-the-art Industry 4.0 technologies in one specific, though relevant, industrial domain, the Italian mechanical engineering sector, that we investigated submitting a structured questionnaire to a large sample of companies belonging to the Federmeccanica federation (the Italian consortium of the mechanical engineering industry, which represents more than 15,000 firms). Albeit the paradigm of Industry 4.0 clearly embraces the idea of innovation, strategic decisions and the related investments need to be grounded on a reliable picture of the adoption process of innovation: the actual magnitude of the phenomenon and how it is progressing, which technology is attracting the greater interest from business players, and what are the sentiments that explain the observed behaviours. In the next paragraph (Section 2), we briefly present the few available analysis on Industry 4.0 and digital innovation in manufacturing; then we introduce the methodology adopted in our study (Section 3) and the main findings (Section 4). In the last section (Section 5), we draw conclusions from this work and outline a few considerations on the state-of-the-art technology and future prospects in the Italian mechanical engineering sector.

2. Industry 4.0: from rhetoric to data

Despite impressive media coverage, EU activism (Factories of the Future), and being featured in government programs around the world, the topic of Industry 4.0 has not been intensively researched by academics. A reliable and comprehensive picture of its actual diffusion and realistic industrial potential is still missing, beyond the hype of an industrial revolution that has a name even though many observers believe it is yet to happen.

Muscio and Cifolilli (2017) study the diffusion of Industry 4.0 technologies by looking at the European regional networks promoted by the 7th Framework Programme for Research and Technological Development. According to their study, Germany plays a leading role both in terms of project coordination and participation of national firms in collaborative projects; the second tier is led by Spain, Italy, and the United Kingdom, as they hold project leadership in over 40% of cases. France, Greece, the Netherlands, Austria, and Switzerland show lower—although still significant—rates of project coordination and participation, while all other member states lag behind.

When looking at patent data for advanced manufacturing technologies, Europe's strong position is confirmed when we compare its data to that of the US, Japan, and South Korea. However, European strengths lie in the industrial activism of a small group of nations, while many areas play a subordinate role (Walendowski *et al*., 2015).

The Staufen Institute provides data on the spread of knowledge and adoption of Industry 4.0 technologies in several countries, including Germany and Italy. Reports on both countries show that there is a continuous trend towards Industry 4.0 and expected financial targets in the near future, while the biggest concern is the competence of the workforce and insufficient qualification on the management side (Staufen, 2016; Staufen Italia, 2015).

Another reference is PwC's 2016 Global Industry 4.0 Survey (PwC, 2015: 4), according to which:

> *[i]ndustrial leaders are digitising essential functions within their internal vertical operations processes, as well as with their horizontal partners along the value chain. In addition, they are enhancing their product portfolio with digital functionalities and introducing innovative, data-based services.*

In addition, the surveyed companies 'are expecting to dramatically increase their overall level of digitisation. While just 33% rate their company as advanced today, that number jumps to over 70% looking ahead to 2020'.

These findings seem heartening, although available data is not in-depth enough to capture the complexity entailed by the design, adoption, and use issues that are brought to the fore by the integration of these new technologies into existing manufacturing systems.

When we look at Italy, two studies must be mentioned: one has been conducted by the Ministry for Economic Development (MISE, 2018) and another by INAP, Istituto Nazionale per l'Analisi delle Politiche Pubbliche (Cirillo *et al*., 2020). The first research explores a large firm-level survey of Italian businesses (the RIL survey: Rilevazione Imprese e Lavoro) and focus either adoption, critical issues and firm behaviours concerning Industry 4.0 technologies; the research conducted by INAP analyses the determinants of technology adoption, with a focus on work organisation. The picture that emerges from these two analyses portrays the limits of the actual diffusion and adoption of digital technologies in the Italian business world. The large majority of manufacturing firms is not adopting or planning to adopt these technologies in the next few years. These are the 86,9% of the total figure of manufacturing firms according to the Ministry for Economic Development (MISE, 2018). According to this research, a small number of firms adopts at least one technology (8.4%) and another 4.7% has investment plans towards adoption. The picture of adopters is interesting too as these are mostly larger enterprises, whose location is most frequently in the industrial North rather than in the South. Also, these firms are usually focused on a limited number of technologies (62.4% adopts just 1 technology; 25.1% adopts 2 technologies). While the scope of adoption increases with dimension, it is just large firms that embrace the paradigm of Industry 4.0 as an integrated system of adoption of different technologies. The research conducted by INAP confirms this uneven pattern of adoption and the single-technology approach to digitisation of Italian companies. However, this analysis is interesting as it portrays the correlation between workers skills, human capital and on-the-job training on the one end and the adoption of digital enabling technologies of Industry 4.0 on the other. In fact, on average early adopters show a higher share of tertiary educated workers and a more intense use of training activities (Cirillo *et al*., 2020).

3. Methodology

In our analysis we explore the Italian mechanical engineering industry that has been investigated using a specific survey consisting of a structured questionnaire submitted to a large sample of companies belonging to the Federmeccanica federation, the Italian consortium of the mechanical engineering industry, which represents more than 15,000 firms.

The authors, in collaboration with a highly qualified panel of experts[1], administered a questionnaire in order to research the sector and provide a reliable picture of how much businesses know about Industry 4.0, the actual adoption of each technology[2] as well as the willingness to invest, and the expected impact on the organisation[3].

The invitation to participate in the research was sent to the CEOs or to the owners of all Federmeccanica associated firms, covering a population of some 15,000 potential respondents and collecting 527 responses. The response rate seems very low (3.5%) compared to the potential number of respondents; nevertheless, this appears to be the most extensive data collection on Industry 4.0 to date at the European level. Having removed incomplete records, 432 valid responses were obtained. To some degree, these data may suffer from sampling auto-

[1] These were part of a task force of experts created by Federmeccanica with the specific aim of supporting its associates in their transition to Industry 4.0. Each expert was a member or associate of either national or international associations of manufacturers and social partners, manufacturing firms, universities, and research institutions.

[2] The panel identified 11 innovative enabling technologies: mechatronics, robotics, collaborative robotics, Internet of Things, big data analytics, cloud computing, cyber security, additive manufacturing, virtual simulation, nanotechnologies, and smart materials.

[3] The questionnaire included three parts. Part I covered a few preliminary questions aimed at capturing firms' specific characteristics such as their economic activity, reference market, competitive factors, type of management (family-run or external management), geographical scope of their activity (Italian, European, and worldwide) and related revenues, the composition of the workforce, R&D expenditure, intellectual property and patents, manufacturing equipment and ICT investments, and academic partnerships. Part II focused on actual adoption and related issues for each technology, such as the business context in which the adoption took place (management, product development, marketing, and sales), the effects on the organization, the perceived benefits, and the respondents' readiness to invest more. Part III focused on change and future expectations.

selection. If we assume that respondents may be the most committed to the topic, this may lead to an overestimation of adoption intensity.

A detailed description of the sampled firms was compiled with the aim of providing an initial presentation of adopter and non-adopter firms. Working on data collected in the third part of the questionnaire (see Table 3.1), notably Q29, Q30 (firm's expectations), and Q31 (supporting actions), we then investigated firm's expectations and their observations on how the challenges of Industry 4.0 should be tackled. In order to scrutinise the multivariate structure of the responses, we performed an exploratory factor analysis (EFA) on the 20 items included in the three questions. Each item was rated on a five-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree). According to the Keiser criterion,[4] five factors were extracted using the principal component method. With this, we guaranteed that a percentage of the cumulative explained variance greater than 66%. Sampling adequacy and the appropriateness of factor analysis were checked using the Keiser Meyer Olkin index (KMO = 0.884) and Bartlett's sphericity test (p-value < 0.001). Moreover, a varimax rotation allowed for more reliable interpretation of EFA. EFA generated five latent factors. Finally, to check the internal reliability of each extracted factor, we calculated Cronbach's alpha.

Question n. 29: Please rate your agreement (on a scale from 1 = strongly desagree to 5 strongly agree) with the following statements about the effect of Industry 4.0	
Q29_1	Industry 4.0 will increase labour productivity
Q29_2	Industry 4.0 will increase capital productivity
Q29_3	Industry 4.0 will increase total factor productivity
Q29_4	Industry 4.0 will allow enterprises to increase their market share
Q29_5	Industry 4.0 will allow enterprises to protect their market share
Q29_6	Industry 4.0 will allow enterprises to sell their products in a higher and much more profitable price category
Q29_7	Industry 4.0 will allow enterprises to develop their business models
Question n.30: Please rate your agreement (on a scale from 1 = total desagree to 5 total agree) with the following statements about Industry 4.0	
Q30_1	Industry 4.0 is unsuitable for SME's
Q30_2	Industry 4.0 requires huge investments
Q30_3	Industry 4.0 allows big companies to be more agile and therefore "threaten" SMEs
Q30_4	Industry 4.0 allows SMEs to be more efficient and competitive in the market, thus "threatening" big companies
Q30_5	Industry 4.0 enables product customisation which can amplify competitive strength
Q30_6	Industry 4.0 is a passing trend
Q30_7	Industry 4.0 fits well for Germany but not for Italy
Q30_8	Industry 4.0 is important, but it requires skills that we don't have
Q30_9	Those who fail to grasp the opportunities offered by these innovations are likely to be excluded from the market
Question n. 31: Please rate (on a scale from 1 = the lowest strategic value to 5 = the highest one) the following actions which your company can implement to facilitate the change due to Industry 4.0	
Q31_1	Creating synergies throughout the value chain (horizontally and vertically) optimising the relationships with territorial networks
Q31_2	Focusing on staff lifelong learning
Q31_3	Reorganizing its structure in order to ease the development of innovation
Q31_4	Facilitating the transition to the managerial culture

Table 3.1. Questions 29, 30 and 31 about firms' expectations and actions to be implemented.

Furthermore, a zero inflated negative binomial (ZIBN) regression was performed to investigate the determinants of the adoption of digital innovative technologies. To this end, the counting variable generated by the number of innovative technologies adopted by each

[4] Kaiser criterion drops all factors with eigenvalues lower than 1.

firm was introduced as a dependent variable. The five behavioural variables selected by the EFA analysis and some firm specific variables were also included as independent variables.

4. Main findings

The sampled firms are geographically distributed across the five NUTS Italian macro regions[5] (52% in the North West, 19% in the North East, 15% in the Centre, and 14% in the South and Islands). Coverage ratio[6] is about 3.5% with the exception of the North West region, which is slightly underrepresented with a ratio of 2%. A total of 9.5% of the firms in the sample are micro-firms, 40.3% are small-sized, 34.2% are medium-sized, and the remaining 16% are large firms.

The first finding of the research concerns the degree to which Industry 4.0 enabling technologies are currently adopted by the sampled firms. According to the analysis, 64% of the respondents indicated the use of at least one of the 11 enabling technologies included in the research.

Although it may appear far too general, we can still class all of these firms as *adopters* while the remaining 36% are *non-adopters*. When we examine the data more closely, we discover that only 3% of the sampled firms had adopted a single technology, while more than 70% of adopters had integrated between two and six technologies. Furthermore, 7% of adopters had integrated more than nine technologies.

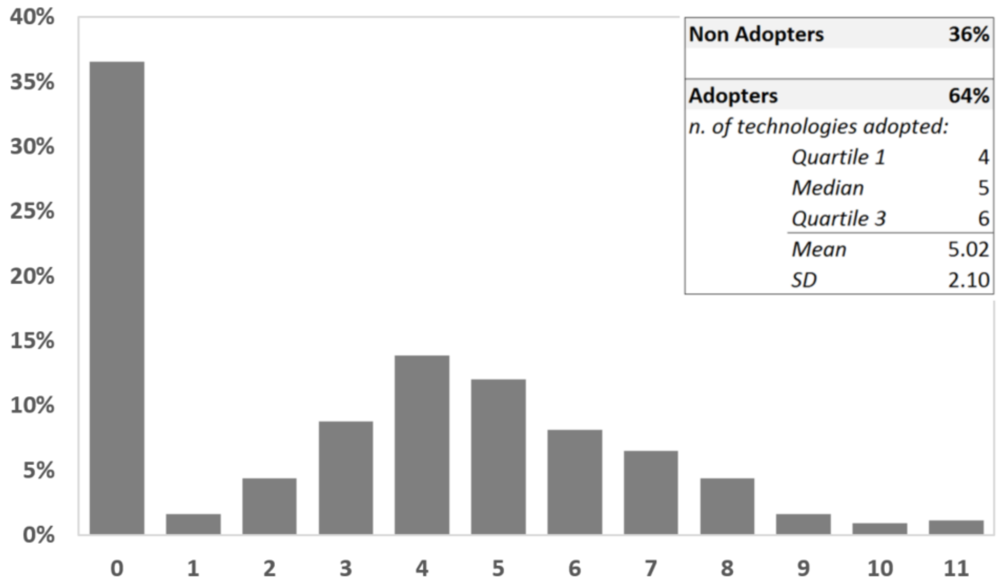

Figure 4.1. Distribution of the number of adopted technologies (complete sample)

As expected, the percentage of adopters increases according to firm size (Jäger *et al*., 2015). Adopters also include more export-oriented firms than non-adopters (44% vs. 33%). They are

[5] NUTS stands for 'Nomenclature des unités territoriales statistiques', the nomenclature of territorial units for statistics developed by the European Union.

[6] The ratio between sample and population size.

larger (median number of employees is 65 for adopters and 30 for non-adopters), show a higher percentage of graduate employees (19% and 12%, respectively) and cooperate much more with research and academic institutions (59% and 26%, respectively).

When we examine each technology closely, the analyses reveal a few interesting details. For example, collaborative robots, big data analytics, nanotechnologies, and intelligent materials are mostly adopted in large companies, while cybersecurity and mechatronics are adopted by either large or small businesses. However, additive manufacturing and cloud computing are adopted by firms with relatively small sales and relatively large workforces. Nanotechnologies, additive manufacturing, and robotics (either collaborative or not) tend to be adopted more in export-oriented firms, while the Internet of Things, cybersecurity, and big data analytics are mostly adopted in firms that are more oriented to domestic markets; firms that adopt nanotechnologies, collaborative robots, and intelligent materials are at the apex of adoption intensity as they adopt the highest number of technologies.

Other interesting observations concern the organisational units in which these technologies are adopted. Cybersecurity, robotics, mechatronics, big data analytics, and collaborative robots are mainly adopted in production activities, while the Internet of things, simulation, nanotechnologies, intelligent materials, and additive manufacturing are mostly adopted in new product development, and cloud computing in service activities. Adoption is sometimes very concentrated, such as robotics used in production, while for other technologies such as cybersecurity, adoption is distributed across different areas including production, development, service, and sales. When we compare adopters and non-adopters, the analysis shows that a few elements are judged more important by the former: product quality, innovation, ability to produce single lots (make-to-order), product personalisation, and ability to sell services associated with the products they sell.

Of special significance is the fact that non-adopters are not planning any significant investment in Industry 4.0 in the coming years, with the only exception being cybersecurity, which could mean a lack of strategy, but which will probably lead to

to an ever-widening gap between adopters and non-adopters in the future.

The EFA generated five factors relating to firms' expectations and their actions to respond to the challenges of Industry 4.0 (see Table 4.1).

	Explained variance (%)	Cronbach's alpha	Factor loadings	Mean	SD
Factor 1: Belief (BELI)	23.97%	0.909			
Industry 4.0 will increase labour productivity			0.785	3.706	1.033
Industry 4.0 will increase capital productivity			0.847	3.412	1.009
Industry 4.0 will increase total factor productivity			0.827	3.516	1.019
Industry 4.0 will allow enterprises to increase their market share			0.794	3.167	1.090
Industry 4.0 will allow enterprises to protect their market share			0.761	3.273	1.068
Industry 4.0 will allow enterprises to sell their products in a higher and much more profitable price category			0.731	3.097	1.107
Industry 4.0 will allow enterprises to develop their business models			0.613	3.331	1.150
Factor 2: Proactivity (PROA)	14.43%	0.834			
Creating synergies throughout the value chain (horizontally and vertically) optimising the relationships with territorial networks			0.681	3.292	1.121
Focusing on staff lifelong learning			0.827	3.845	0.997
Reorganizing its structure in order to ease the development of innovation			0.826	3.764	0.968
Facilitating the transition to the managerial culture			0.800	3.563	1.095
Factor 3: Fear (FEAR)	12.07%	0.741			
Industry 4.0 is unsuitable for SME's			0.713	2.579	1.195
Industry 4.0 requires huge investments			0.798	2.824	1.056
Industry 4.0 allows big companies to be more agile and therefore "threaten" SMEs			0.744	2.947	1.129
Industry 4.0 is important, but it requires skills that we don't have			0.597	2.699	1.200
Factor 4: Skepticism (SKEP)	8.17%	0.715			
Industry 4.0 is a passing trend			0.797	1.875	1.007
Industry 4.0 fits well for Germany but not for Italy			0.743	1.789	1.028
Factor 5: Requirement (REQU)	7.75%	0.640			
Industry 4.0 allows SMEs to be more efficient and competitive in the market, thus "threatening" big companies			0.787	2.933	1.032
Industry 4.0 enables product customisation which can amplify competitive strength			0.538	3.347	1.035
Those who fail to grasp the opportunities offered by these innovations are likely to be excluded from the market			0.519	3.255	1.144

Table 4.1. Results of exploratory factor analysis (EFA) on 20 questionnaire items.

Note: factor loadings less than 0.5 are not reported.

Factor 1 ('Belief') completely overlapped question Q29. As described in Table 4.1, all seven items dealt with the expected benefits of Industry 4.0, such as an increase in productivity, market share, and profitability. This first factor has been labelled 'Belief' as firms that score high in this factor indicated that they strongly believe that Industry 4.0 would generate advantages for their business. The internal consistency is excellent as the Cronbach's Alpha (α) for this factor is 0.909.

Factor 2 ('Proactivity') completely overlapped Q31. All the four items relating to this topic depict firms' propensity to implement actions to facilitate Industry 4.0 change; hence, we decided to label it 'Proactivity'. The internal consistency is quite high ($\alpha = 0.834$).

Question Q30 was split into three different factors. Factor 3 ('Fear') includes four items, which underline the potential risks and threats connected to Industry 4.0. Factor 4 ('Skepticism') comprises two items that represent the general attitude of the respondent, that Industry 4.0 is viewed as a passing trend and that it is not relevant for Italy. Both these factors had an acceptable internal consistency (respectively $\alpha = 0.741$ and $\alpha = 0.715$).

Factor 5 ('Requirement') summarises the three items of Q30, which seem somewhat connected to a fatalist approach, where the respondent views Industry 4.0 as if it is in fact some kind of 'Requirement' or an unavoidable change. Even though Factor 5 exhibited moderate internal consistency (α = 0.640), we decided to treat it as relevant in order to depict the passive attitude that some companies have developed towards Industry 4.0.

What we find in this research is interesting as a few sentiments seem to represent the current infancy of Industry 4.0. Adopters' investment orientation appears to be dependent on some form of ideal commitment to the topic; belief and proactivity explain over 38% of observed behaviours.

Regression analysis was performed to investigate the determinants of digital innovative technologies adoption. As a dependent variable, we introduced the count variable 'Adoption' (ADOP), generated by the number of innovative technologies adopted by respondents. Due to the intrinsic nature of the dependent variable (over-dispersed and characterised by the presence of a high percentage of zero counts), a zero inflated negative binomial (ZIBN) regression model was used. Independent variables include the five behavioural variables (BELI, PROA, FEAR, SKEP, REQU) calculated as factor scores generated from the EFA analysis.

In addition, some firm specific variables were included in the regression analysis as they have already been identified in the existing literature as relevant drivers for innovation adoption (Hong *et al*., 2012). These are related to firms' characteristics, such as size (SIZE), export status (EXPO), and ownership (OWNE). In particular, the log transformation of the number of employees was used to evaluate firm size (SIZE), both as an independent variable and as an inflation variable. Export status has been evaluated taking into account export intensity as a percentage of revenues. In this study, a categorisation of this variable has been introduced by splitting the variable range into two classes (EXPO1: percentage of revenues < 25%; EXPO2: > 25%). OWNE is a four-level categorical variable, which specifies the firm's management (OWNE1: 'family business', OWNE2: 'external management', OWNE3: 'joint management', and a residual category OWNE4: 'other').

As previously mentioned, a ZIBN regression model was adopted. ZIBN models were introduced by Lambert (1992) in order to address the problem of data containing an excessive number of zero observations. Zero inflated models are used when a 'zero' observation can arise from two different situations, either the failure to observe an event or the inability to observe an event (Washington *et al*., 2003). The ZINB regression model uses the following formula:

$$\begin{cases} y_i = 0\, p_i + (1-p_i)\left(\dfrac{1/\alpha}{\dfrac{1}{\alpha}+\lambda_i}\right)^{1/\alpha} \\ y_i = y\,(1-p_i)\left(\dfrac{\Gamma\left(\dfrac{1}{\alpha}+y\right) u_i^{\frac{1}{\alpha}}(1-u_i)^y}{\Gamma\left(\dfrac{1}{\alpha}\right) y!}\right) \end{cases}$$

where y = 1, 2, 3,…, λ_i is the expected number of events per period (as a function of explanatory variables: $\lambda_i = \exp\,(\boldsymbol{\beta X_i})$), α is the over-dispersion parameter, $\Gamma(.)$ is the Gamma function, and $u_i = (1/\alpha)/(1/\alpha+\lambda_i)$. In order to estimate the parameters, the maximum likelihood method was used.

The explanatory capacity of the models is confirmed by the likelihood ratio (LR) test statistic, which tests the null hypothesis that all regression coefficients in the model are simultaneously equal to zero (p-value<0.0001).

In order to compare the zero-inflated negative binomial (ZIBN) model to a standard negative binomial (NB) model, we used the Vuong Test. In our model, the z-values are significant (p-value<0.01), therefore, the Vuong test shows that the zero-inflated negative binomial is better than the standard negative binomial. As reported in Table 4.2, the likelihood ratio chi-square test on the over-dispersion parameter alpha is not significant. In this case, the model could be reduced to a Poisson model. However, the zero inflated Poisson (ZIP) model confirms all the outcomes reported in Table 4.2.

Count model coefficients (negbin with log link)			
Variable	**Estimate**	**SE**	**Significance**
SIZE	0.0455	0.0188	**
EXPO2	0.1548	0.6503	**
OWNE1	-0.1473	0.0817	***
OWNE2	-0.1028	0.0879	
OWNE3	-0.1127	0.0942	
BELI	0.1193	0.0322	***
PROA	0.0612	0.3302	*
FEAR	-0.0821	0.3049	***
SKEP	-0.0377	0.3293	
REQU	0.0365	0.0271	
constant	1.3370	0.1138	***
Zero-inflation model coefficients (binomial with logit link)			
Variable	**Estimate**	**SE**	**Significance**
SIZE	-0.4334	0.0820	***
constant	1.0785	0.3293	***
alpha	2.02E-08	5.65E-06	
LR alpha =0; Chi2 = 0.00; p.value = 1			
Log likelihood = -804.89			
LR Chi2 = 52.10 ***			
Vuong test ZIBN vs NB: z = 14.00 ***			
*p-values codes: *p < 0.05; **p < 0.01; ***p < 0.001*			

Table 4.2. Zero-inflated negative binomial (*ZINB)* regression model outcomes.

The values and the significance of the ZIBN coefficients show that the inflation variable SIZE is significant (p-value<0.01), which demonstrates that the inflation of zeros is due to firm size and that the probability of adopting none of the enabling technologies is negatively related to a firm's size. Therefore, as size increases, the probability of non-adoption decreases.

The variable SIZE is also reported in the list of covariates, which influences the number of enabling technologies adopted. It is significantly and positively related, so the adoption (in terms of number of technologies adopted) increases in line with firm size. Again, the largest adopters tend to adopt more technologies.

Internationalisation is a significant factor that positively influences the number of adopted technologies. The variable EXPO presents a positive and significant coefficient for the level EXPO2, '% of revenues from export > 25%'. Thus, the more firms are open to external markets, the larger the number of adopted technologies.

With regards to the OWNE variable, it is interesting to note that only the category OWNE1: 'family business', is significantly and negatively related, and thus, firms belonging to this category tend to be less inclined towards adoption.

Finally, observing the coefficients related to the five behavioural factors extracted from EFA analysis, only three results were significant. BELI and PROA are positively related to the number of technologies adopted, whereas FEAR is negatively related. It is no surprise that firms that believe in the innovative power of Industry 4.0 and are more proactive toward these innovations show higher levels of technology intensity, while the opposite occurs when firms focus on the potential risks and threats connected to Industry 4.0 rather than the possible advantages.

5. Conclusions

Industry 4.0 is taking its first steps in the realm of manufacturing and the economy. After almost a decade of economic crisis and a rather longer period when manufacturing was on the periphery of the economic and political debate, there are tangible signs that things are changing.

In this paper we aimed at providing a picture of what is happening in the business world, where Industry 4.0 technologies seem to have the highest potential for application. The research is of course limited as we selected one specific, though relevant, industrial domain, the Italian mechanical engineering.

The analysis shows the magnitude of a phenomenon that has undoubtedly been subject to some excessive rhetoric. Nevertheless, some movement is discernible, and things are progressing as the early adopters of the enabling Industry 4.0 technologies are beginning to invest in and develop strategic plans for future action. General purpose technologies such as cybersecurity platforms or mechatronics devices are attracting greater interest from business players. However, if we look at our data, adoption intensity is not low, as many firms are taking the next step and integrating more technologies into their manufacturing systems.

In the early stage of what many call a revolution, sentiments such as belief and proactivity seem to play a vital part in explaining the observed behaviours. What emerges from the research is that a few pioneers are leading the group of early adopters and, not surprisingly, these are mostly large businesses, which are very active in the international markets and highly connected with the research world. Such a finding does not imply any assessment about the causality relationship: large exporting firms could face a tougher competition in foreign markets and thus be forced into quicker and bolder innovation; on the contrary, it is also possible the very ability to adopt new technologies is a habilitating factor for success both domestically and internationally. Further research could address this issue. Apart from the leaders of Industry 4.0, most players—small-sized, family-owned enterprises—are simply looking on indecisively and passively. This could be associated with the fact that managerial skills are poorer in small size, family led companies (Schivardi and Schmitz, 2020) and with the fact that small size firms tend to be under-capitalised (De Socio and Finaldi Russo, 2016): they have a larger debt to equity ratio that could come from families fearing to lose the control over the firms they own. This is particularly worrying because these firms are the bedrock of the Italian economy and many of them do not appear to have a strategy in approaching Industry 4.0 or any plan for getting on board in the near future.

The policy implication is for fiscal incentives for merges among micro/small size firms, for acquisition of small firms and for a capital structure that is more balanced towards equity.

Keywords

industry 4.0; digital innovation; advanced manufacturing; mechanical engineering; Italy

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