The synergic effect of Industry 4.0 technologies on the operations performance. Evidence from Italy.

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Abstract

The aim of this paper is twofold. On the one hand, we want to understand whether Industry 4.0 technologies can positively affect the performance of operations processes. On the other hand, we aim at checking whether technological solutions known as Industry 4.0 are connected to each other by a synergic relationship or, on the contrary, they can be seen as stand-alone solutions, the effectiveness of which does not rely on the adoption of the others. Preliminary findings from a survey show that Industry 4.0 solutions do affect most manufacturing performances and that a synergic relationship among them can be observed.

Keywords: Industry 4.0, Digital Transformation, Performance

Introduction

The recent diffusion of technological solutions (as robotics, 3D printers, augmented reality, automated-guided-vehicles, Internet of Things, big data) peculiar to the so-called Industry 4.0 paradigm (Kagermann et al., 2011) is rising much interest among scholars. Namely, while national agencies, consulting companies and providers of such solutions claim that they can deeply change industrial processes and improve their performance, still there is no clear evidence about the outcome achievable through these investments. Nevertheless, many companies are adopting Industry 4.0 technologies, sometimes without a specific strategic goal.

Building on extant contributions, we test the hypotheses that Industry 4.0 technological solutions can positively affect manufacturing and logistic performance and that they can be considered as pillars of a whole paradigm that drives the transformation of the manufacturing and logistics system. As a consequence, companies should invest jointly in all of them in order to get the most out of such investments.

In the remainder of this paper, we briefly outline the relevant literature on this topic. Then we report on the preliminary findings of a survey carried out among companies located in Italy. Finally, conclusions are drawn.

Literature Review

Industry 4.0 is a new expression proposed in Germany and launched in 2011 by the German Federal Government (Kagermann et al., 2011). It refers to the new fourth industrial revolution, after the first one based on water and steam-powered machines, the second one based on electricity and third one based on electronics and information technology. Industry 4.0 strongly emphasises Cyber Physical Systems (CPS) with an integration of machinery, factory and business processes, which are capable of autonomously exchanging information, activating actions and making decisions and controlling each other independently (Kagermann et al., 2013). In order to re-design a manufacturing system according to the Industry 4.0 paradigm, the adoption of a wide number of technological solutions is considered necessary, which range from Additive Manufacturing, to Internet-of-Things (IoT), Cloud Computing and Big Data Analytics, to mention a few (The Boston Consulting Group, 2015). This feature represents a remarkable difference between the fourth industrial revolution and the previous ones, all of which were based on the development and use of a single technology. In this new setting, planning investments in new technologies becomes complex, in that companies must decide whether to invest in all of them jointly or to identify a priority list of adoption.

The discussion on how to plan improvement projects in a manufacturing environment dates back to the ‘60s, when Wickham Skinner (1969; 1974) challenged the conventional approach according to which manufacturing plants should focus just on productivity. Indeed, operational performance can be seen as a bundle of attributes concerning not only productivity, but also fast and dependable delivery times, product quality, manufacturing flexibility. Because companies cannot do well in each performance attribute, they have to decide what they need to be good at, hence focusing on a specific area of improvement that should be selected on the basis of the competitive model of the firm. Skinner’s “focused factory” paradigm is the theoretical foundation of all contributions that eventually called for the need to adopt a “strategic fit” or “strategic alignment” approach in the design and management of the production system (Sardana et al., 2016; Walter et al., 2013; Wagner et al., 2012; Xiaosong Peng et al., 2011; Ketokivi and Schroeder, 2004; Joshi et al., 2003).

Although this approach is still acknowledged as a cornerstone in the identification of operational improvement priorities, some barriers to its successful implementation have been reported. In particular it has been pointed out that improvement objectives set by functional managers are frequently based on the willingness to adopt up-to-date practices and technologies (Schonberger and Brown, 2017), regardless of the actual needs of the company and of its competitive model.

The development of the Industry 4.0 paradigm is posing new questions concerning the approach with which companies should define their improvement projects and plan their investments in new technological solutions. Indeed, if a synergic relationship among these technologies exist, a prioritization seems to be even risky for the company because the partial adoption of Industry 4.0 pillars could sharply reduce its overall potential.

Hence, in this study we aim at understanding whether Industry 4.0 positively affect manufacturing and logistics performance, and whether a synergic relationship exist among all its pillars. This evidence would have remarkable managerial implications concerning the way in which companies plan investments in Industry 4.0 technologies.

Methodology

To answer our research questions, we carried out a survey (Forza, 2002). It was targeted to companies with facilities in Italy, the experience of which in Industry 4.0 adoption can be considered particularly relevant for this study. Indeed, due to fiscal incentives, several Italian firms are investing in these new technologies. Furthermore, the adoption of Industry 4.0 solutions is also boosted by the fact that Italian firms are on average endowed with relatively obsolete pieces of industrial equipment. These phenomena can lead to investment decisions which are not strictly aligned with the real strategic needs of the company.

We developed a questionnaire in order to collect data among industrial companies that could potentially be interested in the adoption of Industry 4.0 technologies. On top of descriptive information on the company and on the respondent, the questionnaire asked questions on the following issues:

- Whether companies are adopting or have already adopted Industry 4.0 solutions. We classified such solutions as follows: Big Data Analytics; Digital Supply Chain; Internet of Things; Cloud Computing; Robotics; 3D Printing; Automated-Guided-Vehicles;
- The extent to which Industry 4.0 technologies can affect specific performance attributes. We considered the following performances (Joshi et al., 2003): quality of conformance; quality of design; cost; flexibility; delivery. Furthermore, we also wanted to investigate the impact of Industry 4.0 on the ability of manufacturing companies to pursue a servitization strategy (Belvedere et al., 2013) and on social and environmental sustainability (Belvedere and Grando, 2017). For these 20 questions, an assessment on a 1 to 5 Likert scale was requested.

Insofar, 82 usable questionnaires have been collected, with a redemption rate of nearly 8%.

Preliminary Findings

As can be seen in Table 1, the preliminary findings of this survey highlight that the majority of sampled companies are investing or have already invested in the technologies reported in the questionnaire, with the only exception of 3D printers, adopted only by 41.5% of the firms. The highest frequencies of adoption are reported by "Cloud computing" (79.3%), "Digital supply chain" (78.0%), and "Internet of Things" (76.8%).

Table 1 – Frequency of adoption of Industry 4.0 technologies

Industry 4.0 technologies	*Frequency of adoption*
Big data analytics	62.2
Digital supply chain	78.0
Internet of Things	76.8
Cloud computing	79.3
Robotics	75.6
3D printing	41.5
AGV –automated guided vehicles	50.0

Due to the wide variety of technologies that follow under the Industry 4.0 paradigm, we decided to carry out an exploratory factor analysis on their frequency of adoption, in order to see whether homogeneous groups can be highlighted, which can be used for an easier interpretation of the investment patterns undertaken by the sampled companies.

This factor analysis was carried out according to the prescriptions of Hair et al. (2006). Thus we retained only factors with an Eigenvalue higher than 1. Furthermore, to interpret such factors, we focused on those questionnaire items (i.e. technological solutions) with a loading factor higher than 0.5. This analysis pointed out the existence of two factors, as can be seen in Table 2.

Table 2 – Factor analysis on the frequency of adoption of Industry 4.0 technologies

Industry 4.0 technologies	*Factor 1 (Software)*	*Factor 2 (Hardware)*
Cloud computing	.840	
Internet of Things	.690	
Digital supply chain	.687	
Robotics		.778
3D printing		.624
AGV – automated guided vehicles		.586
Big data analytics		.503

Table 2 seems to show that all Industry 4.0 solutions included in this study can be grouped into two factors: the first one has been named “Software technologies” and includes “Cloud computing”, “Internet of Things” and “Digital supply chain”; the second has been named “Hardware technologies” and includes all other Industry 4.0 solutions considered in this study. In this second factor, only the presence of “Big data analytics” should be better interpreted, since it is not a hardware technology. However, because the adoption of more advanced and automated pieces of equipment at the shoop-floor level can result in the availability of data concerning the operating conditions of the machines, Big data analytics could be seen as a way to leverage the potential embedded into such data.

In order to investigate about the impact of these two groups of technologies on the manufacturing and logistics performance, first of all we carried out a confirmatory factor analysis on the 20 questionnaire items aimed at quantifying the following attributes (Belvedere and Grando, 2017; Belvedere et al., 2013; Joshi et al., 2003):

- Quality of design;
- Quality of conformance;
- Flexibility;
- Cost;
- Delivery;
- Environmental and social sustainability;
- Value-added services (servitization).

The outcomes of our confirmatory factor analysis support the hypotheses that the questionnaire items, based on existing scales and used to measure the above attributes, are sound. Furthermore, for each of them we computed the Cronbach’s Alpha in order to measure the reliability of the scales. In all cases, this value is higher than the conventional threshold set at 0.7 (Nunnally, 1978), ranging from 0.703 (Cost) to 0.884 (Environmental and social sustainability). The only exception refers to Quality of conformance, whose alpha, being equal to 0.475, does not support the reliability of this construct.

We computed the means for all performance attributes, on the basis of the assessment (on a 1 to 5 Likert scale) provided by the respondents concerning the ability of Industry 4.0 technologies to positively affect them (see Table 3).

Table 3 – Impact of Industry 4.0 technologies on performance attributes: means

Performance attributes	*Means*
Quality of conformance	3.87
Quality of design	3.77
Flexibility	3.86
Cost	4.04
Delivery	4.12
Environmental and social sustainability	2.75
Value-added services (servitization)	4.01

As can be seen in Table 3, according to the sampled companies Industry 4.0 is going to drive a remarkable positive effect on Delivery (mean: 4.12), followed by Cost (mean: 4.04) and Value-added services (mean: 4.01). On the contrary, it does not seem to be able to determine sound improvement in the field of Environmental and social sustainability (mean: 2.75). An ANOVA has been conducted in order to test whether these differences among means are statistically significant. This test provided favourable outcomes.

Then, we have computed the correlation index between performance attributes and the Software and Hardware factors described in Table 2. These values show that Software is significantly and positively correlated with all performance attributes, with the only exception of Environmental and social sustainability. Hardware has positive and statistically significant correlations only with Flexibility and Environmental and social sustainability. This evidence shows an overall higher impact of Software technologies on the manufacturing and logistic performance.

To further investigate on the relationship between Industry 4.0 technologies and performance attributes, we carried out a regression analysis in which, for each performance attribute (dependent variable), we checked for the impact of Software, Hardware as well as for the moderating impact of Hardware on Software. Evidence is briefly reported in Table 4.

Table 4 – Regression analyses: outcomes

Performance attributes	*Significant R^2?*	*Significant positive β coefficient (Software)?*	*Significant positive β coefficient (Hardware)?*	*Significant positive β coefficient (Moderation)?*
Quality of conformance	Yes	Yes	No	Yes
Quality of design	Yes	Yes	No	Yes
Flexibility	Yes	Yes	No	No
Cost	Yes	Yes	No	No
Delivery	Yes	Yes	No	Yes
Environmental and social sustainability	No	No	No	No
Value-added services (servitization)	Yes	Yes	No	Yes

Table 4 shows that Software is a statistically significant driver of performances (with positive regression weights), with the only exception of Sustainability. On the contrary, Hardware does not have any direct effect on any performance, but it has a positive moderating effect on Software since it can strengthen its impact on most performance attributes. This moderating effect is statistically significant in four cases (Quality of design, Quality of conformance, Delivery, Servitization).Moreover, our regression analysis demonstrates that the highest impact of Industry 4.0 technologies is on Delivery (R-square equal to 0.592) and Servitization (R-square equal to 0.598).

Conclusions

Our study contributes to the recent discussion on the effectiveness of Industry 4.0 technologies. Namely we demonstrate that they can positively drive most performance attributes of manufacturing and logistics systems. Furthermore, since a critical issue in this field refers to the possibility of adopting either a wide bundle or a limited (and focused) subset of solutions, we show that the former approach can be even preferable, although more costly. This evidence is particularly relevant for those companies that are not yet clear about the way in which Industry 4.0 could contribute to their operations strategy and on the way in which such technologies could strengthen their competitiveness. The wide and pervasive effects of these technologies (as a whole) pointed out by our study demonstrates that their adoption is positive in any manufacturing company, regardless of its specific performance priority and business model. We also show that the use of Industry 4.0 technologies is particularly appropriate in companies willing to enrich their product offering through a superior service level and through value-added services.

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