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Smart factory performance and Industry 4.0

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ABSTRACT

Existing literature on the Industry 4.0 concept does not empirically verify if, how, and for which types of firms, a greater openness to enabling technologies of Industry 4.0 provides further opportunities. This study analyzes the causal relationship between this degree of openness and performance, with an empirical analysis based on a sample representing local manufacturing units. Performance is measured by the extent of opportunities businesses obtain. The degree of openness is investigated using two indicators: breadth, or the number of technologies used; and depth, or the number of value chain stages involved. The regression models demonstrate that: (1) breadth and (2) depth of Industry 4.0 allow greater opportunities, and (3) micro-level local units achieve best performances. Verifying the opportunities for companies with Industry 4.0 is extremely relevant, as investments in Industry 4.0 are high in terms of costs, the acquisition of new skills, and the risks of obsolescence to enable better strategic decisions. This work also provides a scope for future analyses of this topic conducted on panel data. Despite the limited application of Industry 4.0, this study's results can encourage managers and policymakers to implement a wider range of enabling technologies in the various stages of the value chain.

1. Introduction

The fourth Industrial Revolution – or Industry 4.0 (Kagermann et al., 2013) – is changing firms' strategies, organization, business models, value and supply chains, processes, products, skills, and stakeholder relationships. Industry 4.0 has created new opportunities and vulnerabilities that must be managed and governed to positively impact both business and society.

Governments worldwide have realized the importance of this new generation of manufacturing (Reischauer, 2018) with active initiatives, including raising awareness, action plans, support, infrastructure investments, sponsorships, and tax benefits to facilitate its implementation in companies. The industrial plans in Table 1 deserve particular attention.

In addition to industrial plans, research programs have been launched to examine new enabling technologies designed by companies and/or private organizations, such as the Industrial Internet Consortium (Evans and Annunziata, 2012), or with public-private partnerships, such as the Factories of the Future – Horizon 2020 program (European Commission, 2016).

Industry 4.0 has rapidly grown over the last few years, accompanied by an exponential increase in literature on its many enabling technologies – and especially those pertaining to the engineering field. Despite the importance of the Industry 4.0 phenomenon, only a few economic and management studies exist, and these focus on 10 primary topics:

- The phenomenon's diffusion (Chovancová et al., 2018; Sung, 2018).
- The impact of enabling technologies on the global economy, measured through productivity, employment and unemployment, and technological and/or legal changes (Brynjolfsson and McAffee, 2014; Eichhorst et al., 2017).
- Innovation in business models (Arnold et al., 2016; Frank et al., 2019; Gerlitz, 2016; Kiel et al., 2017; Laudien et al., 2016; Müller et al., 2018).
- Improving the value chain (Saucedo-Martínez et al., 2018; Kinzel, 2017).
- Redefining the supply chain (Barata et al., 2018; da Silva et al., 2018; Hoßfeld, 2017).
- Product reconfigurations (Porter and Heppelmann, 2014, 2015).
- New human resources competencies and skills (Kergroach, 2017; Krzywdzinski, 2017).
- Developing communications between people, industrial components (equipment and machinery), and products (Pan et al., 2015) and

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Table. 1
Main countries' industrial plans.

Country	Industrial plan	Reference
Germany	High-Tech Strategy 2020	Kagermann et al. (2013b)
France	*La Nouvelle France Industrielle* (The New Industrial France)	Conseil National de l'Industrie (2013)
United Kingdom	Future of Manufacturing	Foresight (2013)
United States	Advances Manufacturing Partnership	Rafael et al., 2014)
China	Made in China 2025	State Council of China, 2015)
Singapore	Research, Innovation and Enterprise	National Research Foundation (2016)
South Korea	Innovation in Manufacturing 3.0	Kang et al. (2016)
Italy	*Impresa 4.0*	Ministero dello Sviluppo Economico (2017)

extending internal and external networks (Reynolds and Uygun, 2018; Kovács and Kot, 2016).

- Sustainability (Kiel et al., 2017; Birkel et al., 2019).
- Transforming internationalization processes (Zucchella and Strange, 2017; Chiarvesio and Romanello, 2018).
- Performance (Dalenogare et al., 2018; Lee et al., 2015).

Despite the relevance of Industry 4.0 in performance, existing works have investigated this theme through conceptual papers or case studies, and have demonstrated a positive causal relationship between the single pillars of enabling technologies and opportunities. However, literature lacks empirical studies investigating the relationship between the plurality between the pillars of Industry 4.0 enabling technologies and performance. It is necessary to consider that several pillars of Industry 4.0 enabling technologies; these can be implemented individually or through various combinations with different impacts on companies and their relationships.

Therefore, this paper aims to empirically investigate the causal relationship between the degrees of openness toward the pillars of Industry 4.0 enabling technologies and performance (Fig. 1).

The study involves four primary steps: (1) identifying the main characteristics of the pillars of Industry 4.0 enabling technologies, and particularly their definitions and the opportunities they offer; (2) defining the research hypothesis; (3) operationalizing the concepts of openness and performance; and (4) empirically verifying the causal relationship between the degree of openness to Industry 4.0 and performance.

The analysis is conducted using a representative sample of 231 local manufacturing industry units developing the Industry 4.0 concept in Piedmont (northern Italy) in 2018 (see Section 4.1). The Piedmont units provide an excellent not only given their high added value in the manufacturing sector – 24%, versus 17% in Italy overall (Istituto Nazionale di Statistica – ISTAT, 2018) – but also for its position as the first Italian region to adopt 4.0 technologies in 11.8% of its manufacturing companies, versus 8.4% in Italy (*Ministero dello Sviluppo Economico, 2018*).

The paper offers two original contributions to current literature:

- From a methodological perspective, it operationalizes the concept of openness and performance in Industry 4.0. Openness is measured in terms of breadth, or the number of pillars of Industry 4.0 enabling technologies implemented; and depth, or the number of stages in the value chain with these implemented technologies. Performance is measured in terms of the number of opportunities identified by the local manufacturing units.
- From an empirical perspective, the results reveal the units' openness to Industry 4.0. This study uses a set of control variables to describe these different opportunities toward openness according to the characteristics of the local units belonging to different industries.

Regarding its managerial implications, the paper indicates whether and how the pillars of Industry 4.0 enabling technologies should be implemented in companies, and identifies key points concerning companies and governance.

The remainder of this paper is structured as follows: The second section presents the theoretical background, while the third section identifies the research hypothesis. The fourth section describes the methodology, and the fifth section analyzes the research results. The conclusions are then refined with a discussion of the work's implications, limitations, and scope for future research.

2. Theoretical background

2.1. Aim and process of the literature review

The theoretical background is derived from a literature analysis on academic journals in English, identified through four criteria: the *period*, spanning January 2011 (German National Plan) to January 2019; *search terms* synonymous with Industry 4.0or the pillars of enabling technologies; the *research domain*, or business economics; and the *research areas*, or economics, business, and management. The literature review of 249 articles identified the origins and definitions of Industry 4.0, as well as the key factors and opportunities related to the pillars of its enabling technologies.

2.2. Origins and definitions of Industry 4.0

Industry 4.0 is a controversial process by nature and definition given the enabling technologies that allow it to exist as well as the opportunities it brings.

The expression "fourth Industrial Revolution" was first introduced in 1988 to identify the processes of evolving inventions into innovation due to scientists on production teams (Rostow, 1988). The term was then associated to the development and application of nanotechnologies (Parthasarathi and Thilagavathi, 2011; Hung et al., 2012). In 2011, this was named "Industry 4.0″ after Germany's "*Industrie* 4.0″ industrial plan (Kagermann et al., 2013b). Other countries have different names for Industry 4.0, such as the "Industrial Internet" or "Advanced Manufacturing" in the United States, "Factories of the Future" by the European Commission, and the "Future of Manufacturing" in the United Kingdom. Other such terms include the "Fourth Industrial Revolution," "Digital Factory," "Digital Manufacturing," "Smart Factory,"

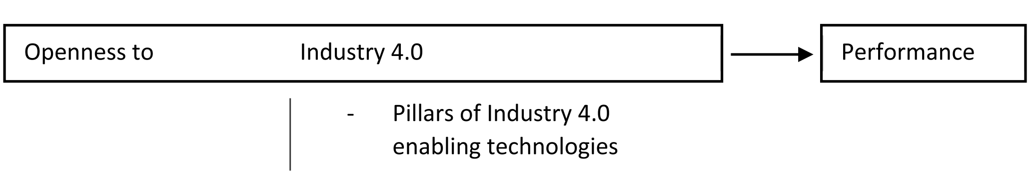

Fig. 1. Conceptual framework.

"Interconnected Factory," "Integrated Industry," "Production 4.0," and "Human-Machine Cooperation."

No conceptual, operative, or universally accepted definition of Industry 4.0 has been identified thus far due to the following: First, Industry 4.0 is comprised of an estimated more than 1200 enabling technologies (Chiarello et al., 2018). Further, its innovations rapidly become obsolete; it can be applied in a variety of domains, such as smart factories, cities, grids, health applications, homes, spaces, objects, or machines; and different disciplines have analyzed the subject, such as engineering, economics, and management, among others. Moreover, its various stakeholders – such as policymakers, managers, entrepreneurs, and academics – have diverse needs.

However, it is possible to determine certain common elements, such as automation systems, connections between the physical and virtual worlds, the recognizing of a set of enabling technologies, digitalization, the Internet, and changes in the relationships with stakeholders and in governance; these will assist in determining a definition to better encompass the phenomenon. The "Industry 4.0″ expression ultimately involves adopting industrial automation systems that assist in managing the value and supply chains, and more widely manage all their related processes (Liao et al., 2017; Reischauer, 2018; Yin et al., 2017).

2.3. Determiners and enabling technologies

The two key factors for Industry 4.0's success are integration and interoperability (Lu, 2017; Lasi et al., 2014; Wei et al., 2017). Integrating industrial automation systems – such as Cyber Physical System (CPS) and Cyber Physical Production System (CPPS) —results in greater and more innovative features through networking with stakeholders, both horizontally and vertically). It also helps to create connections between the cyber and physical worlds. Moreover, interoperability facilitates production processes, even without continuity, within and beyond the boundaries of a business to interconnect systems and exchange knowledge and skills.

Industry 4.0 in particular uses a series of enabling technologies that can be categorized into 10 pillars. The first nine pillars come from a study by the Boston Consulting Group (Gerbert et al., 2015), while some authors (Wan et al., 2015; Kinsy et al., 2011) add an "others enabling technologies" category. This latter category includes a series of equally significant innovations, but with limited application domains, such as agrifood, bio-based economics, and technologies supporting the optimization of energy consumption (Maksimchuk and Pershina, 2017).

2.4. Opportunities of Industry 4.0

The opportunities of Industry 4.0 can be classified into six main typologies (Table 2): production flexibility, which occurs during the manufacturing of small lots; the speed of serial prototypes; greater output capacity; reduced set-up costs and fewer errors and machine downtimes; higher product quality and less rejected production; and customers' improved opinion of products.

3. The research hypotheses

The hypotheses to be discussed in Sections 3.1 and 3.2 are taken from Industry 4.0 literature, while the hypotheses discussed in Section 3.3 are the authors' original construction.

3.1. Opportunities of openness to the pillars of enabling technologies

Existing literature on Industry 4.0 as identified in the theoretical background uses conceptual studies to highlight case studies and laboratory experiments and determine how the openness to individual pillars of enabling technologies provides increased opportunities (Table 1). Additionally, Vogel-Heuser and Hess (2016) demonstrate that more than one of these pillars should be applied to the various stages in the value chain to obtain greater opportunities. Therefore, it can be affirmed that openness can be measured in terms of the number of enabling technologies adopted – breadth – and/or number of stages in the value chain in which these technologies are implemented – depth (Fig. 2).

Thus, two research hypotheses can be assumed:

Hypothesis 1a – Breadth helps companies obtain greater opportunities when applying the pillars of Industry 4.0 enabling technologies.

Hypothesis 2a – Depth helps companies obtain greater opportunities when applying the pillars of Industry 4.0 enabling technologies.

Management literature regarding innovation in general – and Koput's model (Koput, 1997) of innovative search and the attention-based theory of the firm in particular – practically confirms that the relationship between being open to innovation and performance is an inverted U-shaped function. Consequently, two additional research hypotheses can be assumed:

Hypothesis 1b – The breadth when applying pillars of Industry 4.0 enabling technologies is curvilinear, with an inverted U shape.

Hypothesis 2b – The depth when applying pillars of Industry 4.0 enabling technologies is curvilinear, with an inverted U shape.

3.2. New opportunities in production capacity

Büchi and Castagnoli (2018) illuminate how Industry 4.0 provides enabling technologies to help companies achieve greater opportunities following improved efficiency (*Scenario I*) and increased production capacity (*Scenarios II* and *III*).

Scenario I. This ranges from a production model based only on manufacturing large quantities of standardized, limited-variety products (*mass production*) with greater efficiency, measured in terms of higher earnings and lower costs, to models that include two other production scenarios.

Scenario II. This involves manufacturing products to satisfy each individual customer's needs, with production efficiency near mass production but in limited numbers (*mass customization*; Fogliatto et al., 2012; Tseng, Jiao, and Wang, 2010).

Scenario III. Products are manufactured to acquire purchasing experience regarding individual customers' tastes based on their preferences and production volumes, compared to *Scenarios I* and *II* (*mass personalization*; Tseng and Wang, 2010; Chellappa and Sin, 2005).

M*ass customization* and *mass personalization* facilitate variety in the product range, which spans the *many of a kind* to *one of a kind* varieties. This can then be altered over time in response to the growing demand for variety, which consequently results in a further decrease in average unit costs.

Anderson (2004, 2006) defines this method as a "*long tail strategy*," which guarantees companies will profit by selling smaller volumes of customized products that are difficult to find in the market, rather than only selling large volumes of mass-produced products (Brynjolfsson and Smith, 2010). Similar situations have arisen from manufacturing small (*niche*) lots due to *additive manufacturing* (Shapeways, 2015), which can offer on-demand products through 3-D printing.

The current study maintains that unlike larger businesses, smaller firms' mass-production model deters them from obtaining economies of scale and networking, but the latter should obtain greater benefits by adopting enabling technologies. This is because they can adapt their production capacity – even temporarily – to emerging market needs, the time to market, and efficiency and productivity quality standards.

Therefore, the following can be assumed:

Hypothesis 3 – Small companies obtain greater opportunities than larger ones by applying Industry 4.0 technologies.

3.3. The importance of innovation

Given what has been discussed thus far in Section 3, the authors

Table. 2
Pillars of Industry 4.0 enabling technologies 4.0: definition, opportunities, and authors.

Pillars of INDUSTRY 4.0 enabling technologies		Definition	Opportunities	Authors
①	*Advanced manufacturing solutions*	This refers to the creation of interconnected and modular systems that guarantee automated industrial plans. These technologies include automatic material-moving systems and advanced robotics, the latter of which are now on the market as "cobots" (collaborative robots) or automated guided vehicles or unmanned aerial vehicles.	- *Reduces set-up costs, errors, and machine downtimes*, given the capacity to learn tasks from the operator; - *Flexibility*, given by employees' direct participation in the most complex work and control phases and eliminating the structural and technological constraints of automatic and fixed systems; - *Higher production capacity* through the possibility of modifying the criteria, not only to evenly distribute work activities between operator and machine, but also to allow more efficient and effective work.	Chung and Swink (2009); Spanos and Voudouris (2009); Druehl et al., 2018.
②	*Augmented reality*	This involves a series of devices that enriches (or lessens) human sensory perception through the access to virtual environments; this is accompanied by sensory elements, such as sound, smell, or touch. These elements can be added to mobile devices (smartphones, tablets, or PCs) or other sensors to augment vision (augmented-reality glasses), sound (earphones), or touch (gloves) to provide multimedia information.	- *Higher speed in prototyping* through the possibility of designing products and processes with augmented virtual reality; - *The reduction of set-up costs, errors and machine downtime, plus superior product quality and less production waste* due to the possibility of receiving information in real-time and providing virtual training; consequently, this improves work procedures and decision-making processes.	Coxon et al. (2016); Kim et al. (2015); Markopoulos and Hosanagar (2017).
③	*Internet of Things*	This corresponds to a set of devices and intelligent sensors that facilitate communication between people, products, and machines.	- *Higher product evaluations from the customer* due to: a greater knowledge of customer needs and preferences with the aim of personalizing products; including customers in production, or the co-creation of value; and a greater guarantee regarding products' origin, use, and destination, which ensures the product can be effectively traced from the factory to the customer; - *The reduction of set-up costs, errors, and machine downtime, plus superior product quality and less production waste.* This is due to: a greater interconnection along the supply and distribution chains; and the ability to reveal worn or broken machinery in real-time, allowing for proactive maintenance.	Gershenfeld and Euchner (2015); Euchner (2018); Markkanen (2015); Tucker et al. (2018); Porter and Heppelmann (2014, 2015); Manyika et al. (2015); Alqahtani et al. (2019); Vendrell-Herrero et al. (2017).
④	*Big data analytics*	This relates to the technologies that capture, archive, analyze, and disseminate large quantities of data derived from the products, processes, machines, and people interconnected in a company, as well as the environment around it.	- *Higher product evaluations from the customer* due to faster communications, customized products, and the capacity to profile customers and determine their relative needs; - *Flexibility* due to the possibility of demand estimations; - *Better product quality and less production waste*, which optimizes the supply chain due to warehouses' improved efficiency, distribution and sales, and limited production costs.	Lee et al. (2015); McAffee and Brijolfsson (2012a, 2012b); Wamba et al. (2015); Bumblauskas et al. (2017); Wang et al. (2016); He et al. (2017); H. Davenport (2014); Bartosik-Purgat and Ratajczak-Mrożek (2018); Choi (2018); Grover et al. (2018); Lee et al. (2016).
⑤	*Cloud computing*	Cloud computing technologies facilitate the archiving and processing of large quantities of data with high performance in terms of speed, flexibility, and efficiency. Cloud computing also results in a greater number of services developed based on data for a productive system – including monitoring and control functions – to ensure quality and improve operations and production.	The opportunities and risks from using these technologies can be added to those involved in Big Data analytics and Internet of Things technologies.	Mitra et al. (2018); Nieuwenhuis et al. (2018); Mell and Grance (2011); Gottschalk and Kirn (2013); Lal and Bharadwaj (2016); Alshamaila et al. (2013); Kushida et al. (2011); Vaquero et al. (2008); Aoyama and Sakai (2011); Carcary et al. (2014); Sagar et al. (2013); Chen et al. (2014).
⑥	*Cyber security*	This includes security measures designed to protect the flow of information over interconnected corporate systems.	These technologies are designed to support others by limiting the risks linked to the increasing spread of information.	Tuptuk (2018).
⑦	*Additive manufacturing*	This additive production process allows for complex products by creating layers of materials, including such different types of materials as plastics, ceramics, metals, and resins, thus eliminating the need to assemble the material. A significant example is 3-D printing.	- *Higher speed in prototyping* due to faster times in complex design and prototyping phases; - *The reduction of set-up costs, errors, and machine downtimes plus superior product quality and less production waste* by creating small, customized production lots. This is potentially advantageous in terms of its lower production costs and waste. Further, eliminating the separation between manufacturing	Lasi et al. (2014); Weller et al. (2015); Sasson and Johnson (2016); Laplume et al. (2016); Borger et al. (2016); Khorram Niaki and Nonino (2017); Berman (2012); Gibson et al. (2010); D'aveni (2013); Mohr and Khan (2015); Garrett (2014); Rezk et al. (2016); Petrick and Simpson (2013); Beyer (2014); Campbell et al. (2011); Attaran (2017); Reeves (2009); Wigan (2014).

(*continued on next page*)

Table. 2 (*continued*)

	Pillars of INDUSTRY 4.0 enabling technologies	Definition	Opportunities	Authors
			and assembly phases significantly reduces the lead times between orders and deliveries.	
⑧	*Simulation*	This involves reproducing the physical world in virtual models and allowing operators to test and optimize the settings to obtain materials, productive processes (discrete elements), and products (finished or distinct elements).	- *Higher speed in prototyping* that increases production times; - *The reduction of set-up costs, errors, and machine downtimes.*	Guzmán et al. (2012).
⑨	*Horizontal and vertical integration*	The integration offered by Industry 4.0 is characterized by two dimensions: internal versus external. The first (horizontal integration) concerns the integration and exchange of information among the different areas in the company. The second (vertical integration) concerns the company's relationships with its suppliers and customers.	- *The reduction of set-up costs, errors, and machine downtime plus superior product quality and less production waste* due to: lower costs; the ability to self-educate to identify, diagnose, and solve problems; and better connections in the incoming and outgoing supply chains; -*Higher production capacity* and increased productivity.	Anderl et al. (2018); Lu (2017); Xu et al. (2018).
⑩	*Other enabling technologies*	These include several technologies used for specific fields, such as the agrifood and bio-based economy, among others. This also includes the tools to determine where, when, and how energy resources are used with the aim of eliminating or reducing waste.	- *Superior product quality and less production waste* to optimize production and to decrease waste expenses.	Wan et al. (2015); Kinsy et al. (2011).

derive the following original hypotheses by positing that the causal relationship between openness and performance might be influenced by the degree of innovation. Innovation can occur as a part of a high-tech industry and to the propensity of companies to further innovate in Industry 4.0.

Therefore, the following can be assumed:

Hypothesis 4 – High-tech companies obtain greater opportunities than companies in non-high-tech industries by applying Industry 4.0.

Hypothesis 5 – Companies that have already adopted Industry 4.0, and are inclined to further implement Industry 4.0, obtain greater opportunities.

4. Methodology

4.1. Sample

This paper analyzes the secondary data from the *Congiuntura Industriale in Piemonte* dataset collected by the *Unioncamere Piemonte* (2018). The survey data refers to the year 2018, and is obtained from a representative sample of 1331 local units in Piedmont's manufacturing sector (northern Italy), with at least two employees belonging to different size classes and different product sectors. This region case is particularly noteworthy, as it is highly committed to manufacturing (ISTAT, 2018) with a high degree of innovation within Industry 4.0 (*Ministero dello Sviluppo Economico*, 2018). This large-scale industrial survey aims to provide data for an analysis of the manufacturing sector's performance, with a specific theme concentrating on Industry 4.0. The survey's implementation and validation is managed by *Unioncamere Piemonte*. The questionnaire was administered by e-mail to the managers of local manufacturing units between January and April 2018.

The questionnaire contains the local manufacturing units' demographic characteristics, the number of employees, and the sector to which they belong; the thematic section dedicated to Industry 4.0 is composed of five main questions regarding the following areas:

(1) The Adoption of Industry 4.0 (dummy).
(2) Adopted technologies: a list of the 10 pillars of Industry 4.0 enabling technologies (advanced manufacturing, augmented reality, the Internet of Things, Big Data, cloud computing, cyber security, additive manufacturing, simulations, horizontal and vertical integration, and others). Each local unit can adopt one or more of these pillars.
(3) Stages of the value chain: a list of the phases of the value chain in which each pillar is employed, including production, research and development, warehouse logistics, purchasing, sales, and administration.
(4) Future investments: the willingness to further invest in Industry 4.0 (dummy).
(5) Perceived opportunities: a list of opportunities gained by adopting Industry 4.0, as identified in the theoretical background, including: less time from prototype to production, greater productivity through shorter set-up times, the reduction of errors and machine downtimes, better quality and less waste, and greater product competitiveness due to greater product functionality. The "other opportunities" category was ultimately added after validating the theoretical framework through in-depth interviews with managers.

4.2. Econometric measures and model

This research aims to empirically investigate the relationship between the degree of openness to the 10 pillars of Industry 4.0 enabling technologies. This is accomplished through independent variables (*BREADTH* and *DEPTH*) and a dependent variable (*P*, or performance). These concepts are adopted from Vogel-Heuser and Hess' (2016) work and applied to an empirical analysis. Further, different linear and nonlinear regression models contain a set of control variables.

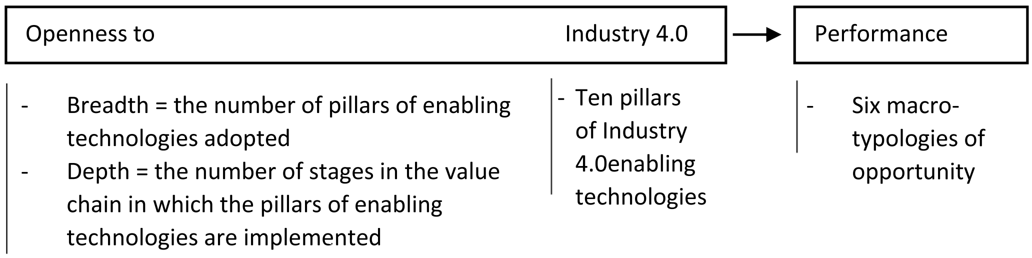

Fig. 2. Operationalizing the conceptual framework.

4.2.1. Dependent variables

The performance variable (*P*) sums the six opportunity variables (Table 1), each of which is a dummy variable coded as zero and one to indicate no opportunities and perceived opportunities, respectively. The six dummies were then summed to obtain an indicator of use, which evaluates the depth of opportunities, ranging from zero (few opportunities to use Industry 4.0) to one (many opportunities).

4.2.2. Independent and control variables

The level of openness towards Industry 4.0 is assessed through the *BREADTH* and *DEPTH* variables identified in Industry 4.0 literature (Vogel-Heuser and Hess, 2016).

The *BREADTH* variable is comprised of a combination of the 10 pillars of Industry 4.0 enabling technologies. Each variable is a dummy variable, coded as zero to indicate these were not implemented, while one indicates these were implemented. The 10 dummies were then summed to obtain an indicator of Industry 4.0 implementation, ranging from one (only one pillar has been adopted) to 10 (all pillars have been implemented). Although the variable is a relatively simple construct, it has a high degree of internal consistency, with a Cronbach's alpha coefficient of 0.8.

The *DEPTH* variable acts as a measure for companies to use Industry 4.0 pillars intensely throughout the value chain; *DEPTH* is comprised of the same 10 pillars as in the previous case, but each of these pillars in this case is a dummy variable coded as zero if Industry 4.0 methods are not used or rarely used in the value chain, and one if they are used frequently. Again, the 10 dummies were then summed to obtain an indicator of use, ranging from and including zero when few pillars have been implemented, to 10 when pillars are frequently used. Although the variable is a relatively simple construct, it has a high degree of internal consistency, with a Cronbach's alpha coefficient of 0.8.

The model uses the following control variables.

- Four *SIZE* variables based on the number of employees (dummy): micro-sized [2–10], small [10–50], medium [50–250], and large [250 +].
- The *HIGH* variable measures the influence of industries with higher technological content, including the chemical, petroleum, and plastic materials; electronics; mechanical; and transportation industries (dummy).
- The *OPEN-ET* variable considers if the local units are inclined to further implement Industry 4.0 (dummy).

5. Results and discussion

5.1. Descriptive analysis

The representative sample is comprised of 1331 local units varying in size and belonging to different industries (Table 3); however, only 15% of the sample has implemented Industry 4.0. Moreover, only 231 local units have adopted one or more pillars of Industry 4.0 enabling technologies in one or more stages of the value chain. On average, 2.7 pillars have been adopted (breadth), and they have been introduced in 0.8 stages in the value chain (depth).

Fig. 3 demonstrates that the openness, breadth, and depth of the pillars are more likely to occur:

- in industries with more frequently used technologies, such as the chemical and oil, plastic material manufacturing, and mechanical engineering and transport industries; and
- in medium-sized and large local units.

The graphs also indicate differentiated situations within the same industry and class size, which highlights an incredibly varied phenomenon according to the local unit surveyed.

5.2. Confirmatory analysis

Table 4 displays the regression analysis results, coefficients, standard errors, statistics χ^2, and p-values. The three columns indicate the regression models adopted with the different variables. The first model is comprised of a linear regression analysis that considers only the effect of the independent variables (*BREADTH* and *DEPTH*) on the dependent variable (*P*). The second model is a linear regression that considers the Model 1 variables as well as the effects of the control variables. These variables concern the size class (*SIZE*), the degree of technology implemented in its industry (*HIGH*) and the local units' openness to further implementing Industry 4.0 (*OPEN-ET*). The third model is obtained by inserting two variables – $BREADTH^2$ and $DEPTH^2$ – to evaluate the relationship's non-linear effects.

The three models confirm Hypotheses 1 and 2, as they report significant coefficients for *BREADTH* and *DEPTH* that are greater than zero. Thus, it has been demonstrated that greater breadth (Hypothesis 1a) and greater depth (Hypothesis 2a) in applying Industry 4.0 result in greater opportunities for local units. However, this is only partially true for Hypothesis 3, as the coefficient in the different size classes is only significant and greater than one for micro-level local units. Therefore, these units obtain greater opportunities than large local units by applying pillars of Industry 4.0 enabling technologies.

In summary, Hypotheses 1b and 2b cannot be confirmed or rejected due to the insignificance of $BREADTH^2$ and $DEPTH^2$. As the results also reject Hypotheses 4 and 5, it can be observed that the degree of innovation does not influence performance.

The analysis also tested the variable inflation factor (VIF) among the independent variables, resulting in a VIF less than 1.6; among the control variables, the VIF is less than 3.6.

5.3. Discussions

Analyzing the representative sample of Piedmont's local manufacturing units reveals a causal relationship between their openness to Industry 4.0 and performance. Further, the descriptive analysis' results make it possible to verify how Industry 4.0 is an emerging phenomenon in Piedmont. Of all the local manufacturing units surveyed, 15% have pursued adoption, measured in terms of the application of at least one pillar of 4.0-enabling technologies. This figure parallels other European areas, and it is higher than the average Italian region, or 8% (Ministero dello Sviluppo Economico, 2018). The Piedmont local manufacturing

Table. 3
The primary indicators of openness to Industry 4.0 by industry and size.

Variable		N. LU	% LU Industry 4.0	LU Industry 4.0 (*n* = = 231) Breadth mean	Depth mean
Industry	1. Food	164	7.9	2.6	0.2
	2. Fabrics, clothing, and footwear	180	11.7	1.8	0.6
	3. Wood and furniture	59	5.1	2.3	0.3
	4. Chemical, petroleum, and plastic materials	121	23.1	3.5	1.3
	5. Metals	294	15.3	2.5	0.5
	6. Electronics	102	17.6	2.2	0.5
	7. Mechanical	208	23.6	3.1	1.1
	8. Transport	61	19.7	3.4	1.5
	9. Other manufacturing sectors	142	8.4	2.2	0.6
Size	Micro [2–10]	422	5.0	1.8	0.7
	Small [10–50]	631	13.6	2.2	0.5
	Medium [50–250]	224	32.6	3.2	1
	Large [250+]	54	38.9	4.3	1.5
Total		1331	–	–	–
Average		–	15.1	2.7	0.8

units' adoption of Industry 4.0 still highlights a gap with Germany's national average, or a 25% adoption rate (BCG, 2018). This gap could be partially attributed to a delay in the nations' implementation of an Industry 4.0 national plan, which occurred in September 2016 in Italy (Ministero dello Sviluppo Economico, 2018), compared to 2011 in Germany (Kagermann et al., 2011). Nevertheless, Piedmont is an important case study because the Italian region is ranked first in adopting Industry 4.0 as well as in its long tradition in the manufacturing sector.

The data on the degree of openness to Industry 4.0 also confirms what was highlighted in a 'conceptual study (Sauter et al., 2016): a strong differentiation depending on the individual economic sector and the size of the manufacturing company. Moreover, local units in high-tech sectors – such as the chemical, petroleum, and plastic materials; metals; electronics; mechanical; and transportation industries – exhibited a higher degree of openness in terms of both breadth and depth.

The confirmatory analysis, conducted through different regression models, verifies a positive relationship between the openness to enabling Industry 4.0 technologies and performance. This empirically confirms what was stated in Vogel-Heuser and Hess' (2016) work.

6. Conclusions

The paper analyzes the causal relationship between the openness to Industry 4.0 and performance. The work is conducted through a confirmatory analysis of the hypotheses based in literature and by constructing and testing new hypotheses. The empirical research is based on a sample of local manufacturing units.

The paper's originality involves: (a) identifying the opportunities to gain technologies enabling Industry 4.0; (b) operationalizing the openness to Industry 4.0 into two concepts – its *breadth* and *depth* – as well as the concept of performance; and (c) verifying the literature used for the hypotheses. Therefore, this empirical analysis reflects what has been mentioned in the Introduction regarding this paper's dual contributions.

From a methodological perspective, this work also operationalizes

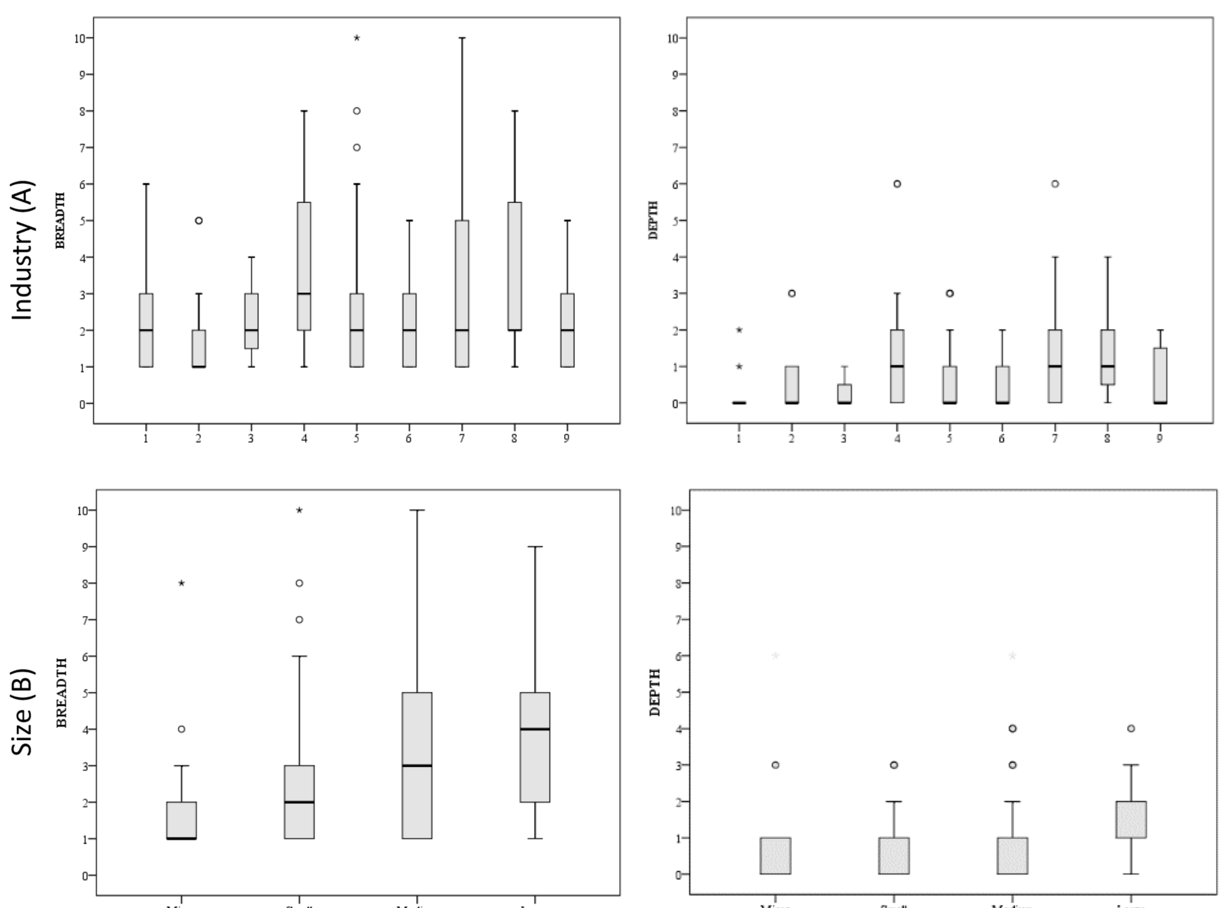

Fig. 3. – Breadth and depth by industry and size (*n* = = 231).

Table. 4
Linear and non-linear regression models.

Model	(1)			(2)			(3)		
	Coeff.	S.E.	*P*-value	Coeff.	S.E.	*P*-value	Coeff.	S.E.	*P*-value
BREADTH	0.372	0.034	***	0.124	0.035	**	0.345	0.101	**
DEPTH	0.175	0.081	*	0.192	0.064	*	0.267	0.131	*
SIZE – micro				1.001	0.207	***	0.839	0.217	***
SIZE – small				0.866	0.120	***	0.647	0.143	**
SIZE – medium				0.766	0.149	***	0.563	0.169	*
HIGH				0.236	0.123	*	0.281	0.128	*
OPEN-ET				0.375	0.126	*	0.153	0.124	
$BREADTH^2$							−0.28	0.012	
$DEPTH^2$							−0.21	0.029	
Number/obs.		231			231			231	
F		162.672	***		97.746	***		79.629	***

*, **, and *** indicate that the coefficients are statistically significant at the < 5%, < 1%, and < 1‰ levels, respectively.

the concepts of openness and performance in Industry 4.0. Empirically, the results indicate the opportunities of openness toward Industry 4.0. The work uses a set of control variables to describe the different opportunities according to the characteristics of the local units belonging to different industries.

The paper theorizes that more open local units – with openness based on the number of enabling technologies or on their application in different stages of the value chain – are more likely to obtain greater opportunities in terms of flexibility, speed, increased production capacity, decreased errors and costs, and an improved product quality and ability to meet customer needs.

The study also confirms that openness leads to better opportunities in the manufacturing industry, while smaller local units are likely to obtain greater opportunities. This is partially justified in Industry 4.0 literature in connection with works examining the internationalization process (Ahokangas et al., 2014; Hmood and Ai-Madi, 2013), small and medium-sized enterprises (Hosseini et al., 2019), and start-ups (Mets and Kelli, 2011). Additionally, other authors posit a link exists between the greater benefits obtained by smaller companies and the possibility to overcome a lack of economies of scale due to mass customization (Fogliatto et al., 2012) and personalization (Tseng et al., 2010; Chellappa and Sin, 2005).

Current results do not clarify whether breaking points exist, after which openness in terms of breadth and depth can negatively influence innovative performance. Finally, the study rejects the hypotheses that innovative industries and the propensity to innovate might influence performance.

6.1. Implications

Despite any political and institutional agendas to develop Industry 4.0 in businesses, the analysis indicates this is a recent phenomenon and has been seldom implemented by businesses, not only in Italy, but also in the first countries to launch such innovation processes. Moreover, it is estimated that only a quarter of German companies have invested in Industry 4.0 (Rüßmann et al., 2015).

As mentioned in the introduction, the paper identifies some managerial implications, indicating whether and how the pillars of enabling technologies should be implemented in companies and identifying key points concerning companies and governance.

The research results first suggest that entrepreneurs should adopt Industry 4.0 in their companies to obtain greater performance. Second, policy-makers should promote mixed incentives that could encourage companies to adopt more enabling technologies in more stages of the value chain.

Finally, the results concerning the emphasis on opportunities to micro manufacturing local units, could allow to forecast that social and institutional environment promoting policies towards cross fertilization between small enterprises and big companies, as well as universities, will be very important in the near future for Piedmont. It is encouraging that regional and local institutions are already moving in this direction.

6.2. Limitations and future research

Innovation research has potentially high costs and commitments to hiring personnel with specific knowledge, competencies, and skills to define the potential of various technologies, customers, and markets without becoming obsolete through innovation. Subsequently, such investments can only be assessed in the long-term. Therefore, the obtained results deserve further confirmatory studies of panel data that assesses the benefits obtained over longer periods of time.

Noteworthy developments could also be obtained regarding the aspects that cannot be investigated using the current database. The most promising lines of research have been identified by applying a regression model that considers different dependent variables to measure the impact of applying Industry 4.0 on companies' results, such as their turnover percentages, improved production capacity, increased employee numbers, lower costs, and/or greater profits.

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Data reference

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Declaration of Competing Interest

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