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Openness to Industry 4.0 and performance: The impact of barriers and incentives

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ABSTRACT

The impact of barriers and incentives on the relationship between openness to Industry 4.0 and performance have so far received little scholarly attention. As a result, this paper explores this relationship by employing a mixed methods approach. A qualitative analysis using in-depth interviews and multiple case studies identifies prominent barriers and incentives, whilst a quantitative analysis on a representative sample of 500 local manufacturing units in Piedmont (a region of Northern Italy) is undertaken via an OLS regression-based path analysis. The results of the parallel-serial multiple mediation model show that: (1) greater openness to Industry 4.0 is related to better performance; (2) greater openness to Industry 4.0 leads to a higher perception of barriers; (3) greater knowledge-related and economic and financial barriers improve performance, abstracting from the adoption of incentives; and (4) greater openness to Industry 4.0 drives the adoption of incentives. However, perceived economic and financial barriers are found not to drive firms to adopt more incentives. The study contributes to the Industry 4.0 literature by identifying previously unidentified strengths and weaknesses to barriers and incentives, and highlights the necessity of policies that reflect real firms' needs.

1. Introduction

In announcing its High-Tech Strategy 2020 Action Plan, the German Government formally started promoting changes in firms that can boost the competitiveness of manufacturers (Kagermann et al., 2013). Academics, managers, and policymakers agree that the adoption of cyber-physical systems and Industry 4.0 technologies in smart factories allows for flexible production, improves supply chains, and leads to more efficient business management, with significant technological, economic, and social impacts (Horváth and Szabó, 2019; Bag et al., 2021). However, this opportunity comes in the context of prominent threats to the future of manufacturing: rapid changes in environmental conditions, changing customer expectations, reduced product lifecycles, and competition between countries.

The majority of previous research (conventions, conferences, and publications) focuses on the analysis of the technological challenges posed the Fourth Industrial Revolution or Industry 4.0 (Oesterreich and Teuteberg, 2016; Pfeiffer, 2017; Frank et al., 2019; Marcucci et al., 2021), and largely ignores the strategic and operational management of firms' performance. In addition, studies have mainly explored the topic through conceptual papers and case studies, thereby identifying a positive relationship between Industry 4.0 adoption and firms' performance but ensuring that empirical research remains in a state of infancy. Only a few authors have carried out confirmatory research on the phenomenon (e.g., Dalenogare et al., 2018, Horváth and Szabó, 2019; Büchi et al., 2020a).

Several authors have noted that the implementation of Industry 4.0 is a complex process and that different firms face a different series of barriers (Kiel et al., 2017b; Dalenogare et al., 2018; Stock et al., 2018; Agostini and Filippini, 2019; Birkel et al., 2019; Horváth and Szabó, 2019; Raj et al., 2020; Ivanov and Dolgui, 2020; Müller et al., 2020), with each barrier causing different impacts on Industry 4.0 adoption and performance. Therefore, it is important to understand these differing effects of the barriers that hinder the adoption of Industry 4.0 technologies as they become increasingly commonplace within firms across the world (Dalenogare et al., 2018).

To overcome these barriers, several industrial plans and public-private partnerships (e.g., *Industrial Internet Consortium* and *Factories of the Future*) have been launched to support Industry 4.0 advancement. However, thus far, individual barriers and incentives have been

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considered separately and without any consistent framework, meaning that little is known about their interdependencies (Kiel et al., 2017b). Therefore, there is a need to identify barriers, incentives, and relationships that could support the development of mitigation strategies, which could themselves induce a smoother adoption of Industry 4.0 technologies (Kamble et al., 2018).

In addition, it is not yet clear, at least from an empirical perspective, to what extent different barriers, different incentives, and firms' characteristics impact the relationship between openness to Industry 4.0 and firm performance. Therefore, despite the benefits that Industry 4.0 technologies provide to firms, there is substantial progress that needs to be made (Dalenogare et al., 2018; Frank et al., 2019). This paper serves to develop this research stream by empirically analyzing the effects of intermediary factors (barriers and incentives) on the causal relationship between openness to Industry 4.0 and firms' performance using qualitative and quantitative analysis (Fig. 1).

The paper identifies performance, barriers, and incentives based on a theoretical background integrated with semi-structured interviews and case studies. The study operationalizes the concept of openness to Industry 4.0 and firms' performance according to the structure formulated by Büchi et al. (2020a):

- Openness to Industry 4.0 is measured in terms of the absolute number of Industry 4.0 technologies adopted; and
- Firms' performance is measured in terms of the absolute number of opportunities perceived by firms when adopting Industry 4.0 technologies.

The study is split into five phases: (1) the identification of intermediary factors; (2) the integration and validation of the theoretical background for Industry 4.0 performance; (3) the definition of research hypotheses; (4) the operationalization of intermediary factors; and (5) empirical tests of the causal relationship between openness to Industry 4.0 and firms' performance considering the various intermediary effects.

The analysis is carried out on a representative sample of 500 manufacturing units in Piedmont (a region of Northern Italy) which implemented one or more Industry 4.0 technologies in 2019. This sample is chosen because of the relevance of the Italian manufacturing sector which, with a turnover of around 900€ billion, is the second largest in Europe, after Germany. Piedmont also has high levels of value added compared to the average for Italy – 24% for Piedmont against 17% for Italy (ISTAT, 2018) – and has a high degree of Industry 4.0 technology implementation in manufacturing compared to the Italian average – 28.9% in Piedmont against 8.4% in Italy (MISE, 2018).

This paper is relevant for four reasons. First, it proposes a more inclusive theoretical approach that takes into consideration barriers and incentives as complements of the relationship between Industry 4.0 and firms' performance. Second, the methodology operationalizes the concepts of barriers and incentives to Industry 4.0. Third, the study empirically identifies the operational dynamics linking openness to Industry 4.0 and performance through an articulated set of intermediary effects. Fourth, the results provide practical advice to entrepreneurs and managers about the barriers and incentives that may hinder or support the implementation of Industry 4.0.

The paper is structured as follows. Section 2 defines and examines Industry 4.0, the concepts of openness and performance, and the factors that influence the studied relationship, as well as stating the research

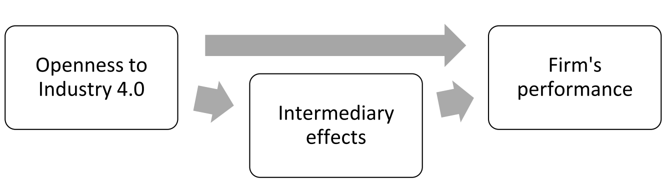

Fig. 1. Conceptual framework.

hypotheses. Section 3 describes the methodology of the qualitative analysis that integrates and validates the theoretical background and a quantitative analysis that tests the hypotheses. Section 4 reports the main results and Section 5 discusses these results. Section 6 highlights the most promising theoretical and practical implications, identifies limitations, and proposes avenues for future research.

2. Theoretical background and hypothesis development

This theoretical background develops the concepts of Industry 4.0, openness to Industry 4.0, performance, barriers, and incentives, and identifies research hypotheses.

The theoretical background is constructed using the following databases: Web of Science (WoS), Scopus, and EBSCO. WoS and Scopus are the most authoritative international sources for academic work in the social sciences (Vieira and Gomes, 2009), guaranteeing an optimal balance between: (1) coverage of existing works; (2) convenience in retrieving papers; and (3) the standardization of information in the database. EBSCO is added to integrate the results, since the EBSCO Information Service is a leading provider of research databases.

Analysis of the English-language literature was undertaken by selecting research that met four criteria.

- *Period*: From January 2011 – the introduction of the German National Plan – to October 2020
- *Keywords*: 17 phrases associated with Industry 4.0 ("Industry 4.0″ OR "4th industrial revolution" OR "Fourth industrial revolution" OR "Factor* of the Future" OR "Future of Manufacturing" OR "Digital Factor*" OR "Digital Manufacturing" OR "Smart Factor*" OR "Interconnected Factor*" OR "Integrated Industr*" OR "Production* 4.0″ OR "Human-Machine-Cooperation*" OR "Industrial Internet" OR "Cyber-physical System*" OR "CPS" OR "Cyber-physical production system*" OR "CPPS"), 5 words or phrases associated with performance ("performance*" OR "opportunit*" OR "benefit*" OR "advantage*" OR "driving force*"), 5 words associated with barriers ("barrier*" OR "obstacle*" OR "disadvantage*" OR "risk**" OR "challenge*") and 2 words associated with incentives ("incentives" OR "measures").
- *Search string*: Used 17 phrases associated with Industry 4.0 AND 5 words or phrases associated with performance AND 5 words associated with barriers AND2 words associated with incentives.
- *Research areas*: A literature review of 316 economic, business, and management papers identified Industry 4.0 definitions and the operationalization of openness to Industry 4.0, performance, barriers, and incentives

The main studies referenced are described in Table 1.

2.1. Industry 4.0

The neologism "Industry 4.0″ is composed of a first part that reflects the historical basis of manufacturing and a second part – "4.0″ – that refers to the fourth phase of the industrialization process (Kagermann et al., 2013).

The development of Industry 4.0 follows the enormous increases in productivity that stemmed from mechanized production plants driven by water and steam energy (mechanization) in the second half of the 18th century, the division of labor and the advent of mass production using electricity (electrification) at the beginning of the 20th century, and the computerization of industrial production by programmable logic controllers (digitalization) in the early 1970s (Shrouf et al., 2014; Wolter et al., 2015; Ghobakhloo, 2018).

The central technological axis of Industry 4.0 is the communication, intermediation, and relationship environment (environment 4.0) realized through cyber-physical systems (CPSs) and/or cyber-physical production systems (CPPSs). Environment 4.0 employs human resources for

Table 1
Summary of the main studies referenced.

Authors' names and year	Approach	Methodology	Units of analysis	Identified performance	Identified barriers
Agostini and Filippini (2019)	Quantitative	Cluster analysis	1000 Italian manufacturing firms	Improved productivity of human resources	None
Birkel et al. (2019)	Qualitative	Literature review and 14 in-depth interviews with experts	German manufacturing firms	None	Economic, social, and environmental risks
Büchi et al. (2020a)	Quantitative	Survey	231 local manufacturing units in Northern Italy	Production flexibility, which occurs during the manufacturing of small lots; the speed of serial prototypes; greater output capacity; lower set-up costs, fewer errors and reduced machine downtimes; higher product quality and fewer rejected products; improved customer opinion of products	None
Calabrese et al. (2020)	Qualitative	39 in-depth interviews	Manufacturing sector	Cost reduction; production time reduction; production line flexibility; productivity; profitability; competitiveness; output quality	Difficulties in employee reorganization; resistance to factory reorganization; large investments; different communications standards among machines of different vendors; vulnerability to cyberattacks; regionally limited infrastructure; flaws in the legal/regulatory framework
Dalenogare et al. (2018)	Quantitative	Regression analysis	2225 manufacturing firms in Brazil	Improved production customization; improvement in product quality; reduction of operational costs; increased productivity; reduction of product launch timeframes; improved sustainability; increased processes; visualization and control; reduced worker satisfaction	None
Horváth and Szabó (2019)	Qualitative	Semi-structured interviews	26 Hungarian manufacturing companies	Growing competition; increased innovation capacity and productivity; expectations of customers; energy-saving efforts and improved sustainability; support for management; opportunity for business model innovation	Human resources and work circumstances; shortage of financial resources; standardization problems; concerns about cybersecurity and data ownership; technological integration; difficulties in coordinating across organizational units; lack of planning skills and activities; organizational resistance
Kiel et al. (2017a)	Qualitative	Semi-structured interviews with experts and analysis of firms' documents	76 manufacturing companies	Increased flexibility; optimized decision making; customization; highly profitable business models; improved work-life balance	None
Kiel et al. (2017b)	Qualitative	In-depth interviews with experts	Manufacturing firms	None	Lack of a skilled workforce, conflicts between workers due to changing working environments; shortage of financial resources; data security; lack of skilled internal human resources; new investments that aggravate the strong demand for internal financial resources; lack of clear standards; organizational resistance
Müller et al. (2018)	Qualitative	In-depth interviews	68 automotive supply, mechanical engineering, electrical engineering, and ICT firms	Increased services; improved customer experience; business model innovation	Particularly costly process due to the level of investment required and the purchase and/or transformation of machinery; need for new skills and organizational and management transformation; lack of skilled internal human resources; new investments that aggravate the strong demand for internal financial resources; lack of clear standards
Müller et al. (2020)	Qualitative	Structural equation model	221 German industrial enterprises	Increasing the efficiency of transactions; chances to develop novel business model designs	None
Raj et al. (2020)	Qualitative	Comprehensive literature review and discussions with industry experts; gray decision-making trial and evaluation laboratory (DEMATEL) approach	Manufacturing sector	None	Large investment into Industry 4.0; lack of clarity regarding economic benefits; challenges in value chain integration; in-branch security risks; low maturity level of desired technologies; inequality; disruption of existing jobs; lack of standards, regulations, and forms of certification; lack of infrastructure; lack of digital skills; challenges in ensuring data quality; lack of internal digital culture and

(*continued on next page*)

Table 1 (*continued*)

Authors' names and year	Approach	Methodology	Units of analysis	Identified performance	Identified barriers
					training; resistance to change; ineffective change management; lack of an associated digital strategy; resource scarcity
Stentoft et al. (2020)	Quantitative	Mixed methods	190 medium-sized Danish manufacturing firms	Reduced costs; improved time-to-market; improved response to customer requirements	Lack of standards; few financial resources; few human resources; lack of understanding of the strategic importance of Industry 4.0; focus on operation at the expense of developing the company (ambidexterity); lack of data protection (cybersecurity); lack of a qualified workforce; lack of knowledge about Industry 4.0; required education of employees; lack of employee readiness; lack of understanding of the interplay between technology and human beings

creative and problem-solving activities, and guarantees its functionality through two key factors: integration and interoperability (Lu, 2017). Integration enables innovative functionalities through network connections between products (primary, intermediate, and final), people (B2C customers and employees), locations (including remote locations), means of production (machines, workpieces, and modules), and partners (suppliers, strategic affiliates, and B2B customers) (Schneider, 2018). Network connections increase productivity through collaboration at the micro- (i.e., people and machines), meso- (i.e., systems and suppliers) and macro- (i.e., enterprises and companies) levels (Korambath et al., 2014; Büchi et al., 2020b). Communication between different stakeholders within the organizational structure and along the value chain facilitates the connection of physical and virtual operations. Interoperability allows for the realization of seamless production both within and beyond the firms' boundaries, through interconnections between production systems and exchanges of knowledge and skills between production structures and across firms.

2.2. Openness to Industry 4.0

Industry 4.0 is implemented through a novel combination of established and new technologies. The type and level of Industry 4.0 technologies' performance depend on their means of application and function, as well as on the departments in which they are utilized. Previous studies identify a wide range of Industry 4.0 technologies: Italian industrial plan identifies 39 (*Impresa 4.0,* MISE, 2017), the French industrial plan identifies 47 (*La Nouvelle France Industrielle,* Conseil National de l'Industrie, 2013), while other works have identified over 1200 technologies (Chiarello et al., 2018). Some studies (e.g., Rüßmann et al., 2015) classify the portfolio of enabling technologies into nine pillars: advanced manufacturing, augmented reality, the internet of things, big data analytics, cloud computing, cyber security, additive manufacturing, simulation, and horizontal and vertical integration. Kinsy et al. (2011) and Wan et al. (2015) add the additional category of *other 4.0 technologies*, which includes a number of equally significant innovations, but with often limited domains of application, such as agri-food, bio-based economics, and technologies supporting the optimization of energy consumption (Maksimchuk and Pershina, 2017).

Industry 4.0 introduced the 10 R processes of advanced production, namely refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover (Bag et al., 2021).

Conceptual studies, case studies, or laboratory experiments on Industry 4.0 have shown that openness to individual pillars of Industry 4.0 technologies offers more opportunities. Vogel-Heuser and Hess (2016) and Büchi et al. (2020a) empirically show that multiple pillars should be applied at various stages of the value chain in order to produce more opportunities. Therefore, there is evidence to suggest that openness to Industry 4.0 should be measured in terms of the number of technologies adopted (i.e., breadth of use), such that this informs our analytical approach.

2.3. Performance

The literature on Industry 4.0 performance demonstrates how openness to Industry 4.0 technologies in one or more phases of the value chain allows firms to improve performance (Vogel-Heuser and Hess, 2016; Büchi et al., 2020a). This performance improvement identified by the literature can be classified into 7 categories (labeled here as 'P' categories), which are reported in Table 1.

2.3.1. P1 production flexibility

Industry 4.0 has been identified as a major determinant for improving production flexibility (Ahuett-Garza and Kurfess, 2018; Cavalcante et al., 2019; Dubey et al., 2019; Frank et al., 2019) through virtualization, decentralization, and network creation (Fragapane et al., 2020).

Additionally, production flexibility can be reached through combinations of mass customization and mass personalization, which necessitate the production of a variety of products. Mass customization involves the creation of products at limited volumes that meet individual customers' needs with a level of efficiency close to that of mass production (Fogliatto et al., 2012), whilst mass personalization is the production of products and purchasing experiences at limited volumes according to individual consumers' preferences (Chellappa and Sin, 2005; Tseng et al., 2010).

2.3.2. P2 speed of serial prototypes

Industry 4.0 allows for the evaluation of the functionality and performance of core and component products and processes through the creation of virtual models. These "digital twins" provide the possibility of examining the performance of products or factories in different contexts and reduce the length of the product and production development process in industrial contexts that are both highly competitive and time-to-market oriented (Lasi et al., 2014; Bauer et al., 2015; Fatorachian and Kazemi, 2021; Moeuf et al., 2020).

2.3.3. P3 greater output capacity

Many of the Industry 4.0 technologies applied to production systems allow for small batch production and production flexibility, thus improving production volumes (Calabrese et al., 2020) by 45–55% (McKinsey, 2019). The lower costs of Industry 4.0 technologies allow creating production environments characterized by higher productivity and greater flexibility along with cost containment (Fragapane et al., 2020). Thanks to the 4.0 environment it is possible to enable efficient mass production, thereby offering increases in overall production levels by combining mass customization and mass personalization. The combination of these scenarios allows companies to operate a long tail strategy (Anderson, 2004, Anderson, 2006), which guarantees higher profits through the production of smaller volumes of customized products which are difficult to find on the market using large volumes of mass-produced products (Brynjolfsson et al., 2010).

2.3.4. P4 reduced set-up costs, fewer errors, and shorter machine downtimes

Industry 4.0 reduces costs, errors, and downtimes through the real-time monitoring of operating conditions for key resources, highlighting efficient downtimes, and communicating these to operators through user-friendly devices (i.e., tablets, smartphones, or smartwatches). This monitoring allows for immediate intervention and the speedy restoration of peak operating conditions (Georgakopoulos et al., 2016). Industry 4.0 allows for the development of predictive maintenance models, based on collected data and subsequent analysis, that offer a means of comparing operational or performance values (i.e., efficiency or compliance) and reduce machine downtime (Hughes et al., 2020). These activities reduce maintenance costs by supporting production management through the supply of information. Firms can therefore employ Industry 4.0 methods to increase supply volumes, achieve significant cost savings, and ensure micro-level performance improvements (Kiel et al., 2017b; Calabrese et al., 2020; Fatorachian and Kazemi, 2021; Stentoft et al., 2020).

2.3.5. P5 higher product quality and fewer rejected products

Industry 4.0 allows for the production of higher quality goods (Porter and Heppelmann, 2014, 2015; Stentoft et al., 2020) and the reduction of waste (Paritala et al., 2017), while significant improvements can also be achieved in energy efficiency (Lins and Oliveira, 2017; Szalavetz, 2019). The literature notes that Industry 4.0 can support the achievement of environmentally sustainable manufacturing with the development of green products, manufacturing processes, and supply chain management structures (de Sousa Jabbour et al., 2018; Müller et al., 2018; Birkel et al., 2019).

2.3.6. P6 customers' improved opinion of products

Industry 4.0 technologies allow firms to develop or increase their comparative advantage over their competitors as the demand for products that are adapted to consumers' expectations and needs increases (Adolph et al., 2014; Karre et al., 2017; Stentoft et al., 2020). Industry 4.0 also raises the degree of customer involvement in products (Kagermann et al., 2013; Ustundag and Cevikcan, 2017), such that Müller et al. (2018) note that Industry 4.0 affects three elements of manufacturing: value creation, value capture, and value offer.

2.3.7. P7 improved productivity of human resources

Djuric et al. (2016) highlight that the implementation of Industry 4.0 enables the greater productivity of human resources due to the raised efficiency of work and the improvement of working conditions through the replacement of humans performing dangerous activities. The increased productivity of human resources can derive from improved skills, greater organizational and collaborative capacity across different areas of the firm, and an ability to learn from each other (Agostini and Filippini, 2019).

Based on the theoretical background, the primary research hypothesis is developed as follows:

H1: Greater openness to Industry 4.0 leads to greater perceived performance.

This is the primary hypothesis, on which all the other hypotheses depend. As such, if this hypothesis is not verified, the study cannot be conducted.

2.4. Barriers

Previous studies highlight several barriers that can hinder the effective implementation of Industry 4.0 technologies. The barriers presented in the literature are separated into 11 types (labeled here as 'B' categories).

2.4.1. B1. Inadequate information on the potential offered by Industry 4.0 technologies

Koch et al. (2014) and Basl's (2017) studies highlight the number of firms that have not implemented Industry 4.0 and do not intend to even produce studies on the economic feasibility of Industry 4.0 technologies due to a lack of information on the potential benefits or drawbacks of its application. In addition, Müller et al. (2018) empirical analysis of a sample of German entrepreneurs shows that implementation of Industry 4.0 technologies is a particularly costly process due to the level of investment required to purchase or transform machinery, the need to acquire new skills, and the necessary organizational and management transformation. Koch et al. (2014), Müller et al. (2018), and Birkel et al. (2019) also show that Industry 4.0 technologies require significant investments which have uncertain amortization schedules and uncertain future uses. Furthermore, Kache and Seuring (2017) state that, in addition to economic investments, major changes in human resource capabilities and processes and technologies at the corporate and local levels are required. Similar results are highlighted by Masood and Sonntag (2020).

2.4.2. B2. Insufficient knowhow within companies

Industry 4.0 changes will ensure that creative and communicative workers become more valuable to companies (Erol et al., 2016) since the challenges that Industry 4.0 poses require continuous innovation and learning, which is dependent upon the capabilities of key personnel (Shamim et al., 2016). Additionally, creativity and innovativeness might be useful in fulfilling customers' requirements (Sriram and Vinodh, 2020). However, such knowledge and skills are not always available to firms (Calabrese et al., 2020). Industry 4.0 adoption requires new skills and knowledge (Ras et al., 2017; Wei et al., 2017) and a highly skilled workforce that is capable of managing the interaction between processes and information flows, and cooperating to solve problems (Balasingham, 2016; Erol et al., 2016). Therefore, one of the main challenges for Industry 4.0 implementation is the lack of skilled internal human resources (Adolph et al., 2014; Karre et al., 2017; Kiel et al., 2017a; Müller & Voigt, 2018). Moreover, the foremost requirement for initiating Industry 4.0 consists of cross-functional collaborations through the interconnection of all elements in the value chain network (Ras et al., 2017; Ghadge et al., 2020). The literature also shows that the employees with different skill levels are important for improving performance (Okorie et al., 2020; WEF, 2020).

2.4.3. B3. Few skills in the labor market

Liboni et al. (2019) note that a major barrier to Industry 4.0 adoption is the lack of a skilled workforce in the labor market (Kumar et al., 2021). SMEs, in particular, are seen to lack the skills that would enable the efficient exploitation of Industry 4.0 technologies (Moeuf et al., 2020). This acts both as a barrier to the development of Industry 4.0 and as a problem in the short to long term given the professional profiles formed in educational institutions at various levels (Baygin et al., 2016; Benešová and Tupa, 2017; Motyl et al., 2017). It is therefore imperative that companies train employees in order to transition to Industry 4.0 production methods (Kagermann et al., 2013). The skills most in demand are: information and data literacy; communication and collaboration, digital content creation, safety and security, and problem solving (Flores et al., 2020).

2.4.4. B4. Insufficient financial resources within the firm

Industry 4.0 requires a significant investment (Kumar et al., 2020) with an uncertain return (Müller et al., 2018) as the rapid evolution of technologies makes these investments risky (Kagermann et al., 2013; Schneider, 2018). Birkel et al. (2019) also highlight the long and uncertain amortization and the high investment required in personnel. This is most noticeable in SMEs where managers tend to favor major investments (Calabrese et al., 2020). Additionally, financial constraints are a significant challenge to adopting Industry 4.0 in terms of the development of an advanced modern infrastructure and sustainable process innovations (Ghadge et al., 2020).

2.4.5. B5. Scarcity of external financing

Kagermann et al. (2013), Müller et al. (2018), Schneider (2018), Birkel et al. (2019), and Calabrese et al. (2020) note that the lack of internal coverage for financial resources ensures that firms often experience difficulties in accessing external capital, which further aggravates other issues.

2.4.6. B6. Insufficient infrastructure

Industry 4.0 uses a combination of CPS-enabling technologies that, through the internet of things – a global network infrastructure composed of many connected elements of sensory, communication, networking, and information processing technologies (Tan and Wang, 2010), enables the creation of virtual networks that support operations in smart factories (Oesterreich and Teuteberg, 2016; Peruzzini et al., 2017; Xu et al., 2018). In order to achieve corporate interconnectivity between suppliers and customers within the value chain and along the supply chain, firms need access to economic infrastructure (primarily broadband internet connections) that enable the various elements – products, devices, people, places, means of production, and partners – to communicate with each other instantaneously. The existence of ICT infrastructure is therefore a prerequisite for Industry 4.0 data transmission and systems integration (Erol et al., 2016). Consequently, having inadequate economic infrastructure poses a serious risk to the competitiveness of firms (Birkel et al., 2019).

2.4.7. B7. Legal uncertainties

The transformation of production centers into smart factories is a long and difficult process, made more complicated by issues relating to legal uncertainties over liability for, and ownership of, personal data and the protection of intellectual property (Birkel et al., 2019). In addition, at the international scale, Industry 4.0 opportunities come with possible vulnerabilities due to differing regulations across countries (Wu and Feng-Kwei, 2015). There remains a need for legislation governing cross-border intra- and inter-firm cooperation and trade, health, safety at work, and working hours (Kiel et al., 2017b; Birkel et al., 2019). Furthermore, security breaches via the sharing of information between partners are a particular concern (Koch et al., 2014).

2.4.8. B8. Difficulties in developing partnerships with universities and research centers

Collaborative strategies for implementing R&D are crucial to the success of any firm. However, as the literature highlights, organizations encounter problems in R&D activities on Industry 4.0 technologies because of difficulties establishing or strengthening partnerships with universities and research centers (Mittal et al., 2018). Such bilateral and multilateral partnerships can help firms (and SMEs especially) to access new opportunities (Müller et al., 2018). However, connecting with multiple partners involves barriers to coordination that require the creation of value networks which enable the development of a profitable and sustainable ecosystem that outputs mutually produced value (Dellermann et al., 2017; Ghanbari et al., 2017). In addition, it is important to create partnerships between firms to acquire new external knowledge and to better develop Industry 4.0 technologies (Müller et al., 2020).

2.4.9. B9. Lack of clear standards

The lack of clear standards (Kovaitė et al., 2020) hinders intra- and inter-firm collaboration and Industry 4.0 technology implementation. Specifically, Industry 4.0 technology adoption can be limited by: low levels of technological integration, particularly within the internet of things (Müller & Voigt, 2017); inadequate security in data transmission, both between organizations and within organizations (Cimini et al., 2017; Kiel et al., 2017a); and the limited reliability and stability of machine-to-machine communications (Varghese and Tandur, 2014; Sung, 2018). Further, the variety of data types and sources, the different standards used across the several partners in a supply chain, and unstandardized interfaces represent challenges to information sharing under Industry 4.0 (Müller et al., 2020). Finally, the lack of trust impedes cross-company information sharing and collaboration in particular in SMEs (Müller et al., 2018).

2.4.10. B10. Organizational resistance

Another primary obstacle to Industry 4.0 adoption is cultural and technical acceptance by human resources (Birkel et al., 2019; Horváth and Szabó, 2019; Theorin et al., 2017). An internal culture of embracing technological advancement must be nurtured throughout the organization to ensure teams are ready to adopt new technologies (Raj et al., 2020).

However, many managers and workers remain unwilling to change their production strategies and tasks (Raj et al., 2020), and in many cases there is a real resistance to new technologies (Haddud et al., 2017). Specifically, this could be because some technologies generate vast amounts of personal data on spending behavior, financial management, domestic habits, and health information, and employees often fear that Industry 4.0 technologies can increase the degree of surveillance over their work (Moeuf et al., 2020).

2.4.11. B11. The firm's sector of operation does not need Industry 4.0 investment

Whilst Industry 4.0 technology adoption offers many concrete advantages in terms of lower costs and higher revenues, these require a considerable amount of resources for implementation (Büchi et al., 2018) and the reorganization of the entire business operation (Raj et al., 2020). Indeed, many firms have not introduced Industry 4.0 technologies and do not intend to produce feasibility studies due to a lack of information about the benefits or drawbacks (Koch et al., 2014; Basl, 2017; Müller et al., 2018), perhaps signifying a belief that the entire sector does not need Industry 4.0 (Birkel et al., 2019; Horváth and Szabó, 2019; Müller et al., 2020; Stentoft et al., 2020).

The theoretical background shows there are 11 barriers to Industry 4.0. These perceived barriers are primarily centered around knowledge issues, economic or financial issues, cultural issues, or system conditions. Hence, the following research hypotheses are posited:

H2a: Greater openness toward Industry 4.0 leads to higher perceived barriers related to knowledge issues.

H2b: Greater openness toward Industry 4.0 leads to higher perceived barriers related to economic or financial issues.

H2c: Greater openness toward Industry 4.0 leads to higher perceived barriers related to cultural issues.

H2d: Greater openness toward Industry 4.0 leads to higher perceived barriers related to system conditions.

Additionally, Dalenogare et al., (2018) show that the different types of barriers have different effects on performance. Therefore, the following hypotheses are proposed:

H3a: Greater perceived barriers related to knowledge issues lead to the perception of improved performance.

H3b: Greater perceived barriers related to economic and financial issues lead to the perception of improved performance.

H3c: Greater perceived barriers related to cultural issues lead to the perception of improved performance.

H3d: Greater perceived barriers related to system conditions lead to the perception of improved performance.

2.5. Incentives

The transformational wave caused by the German Government's *High-Tech Strategy 2020 Action Plan* led many countries to implement industrial plans that improved firms' competitiveness and productivity on the manufacturing sector (Kagermann et al., 2011). At around the same time, the United States launched the *Advanced Manufacturing Partnership* (Rafael et al., 2014), which was followed by France's *Nouvelle France Industrielle* (Conseil National de l'Industrie, 2013) and the United Kingdom's *Future of Manufacturing* (Foresight, 2013). Asian countries' initiatives were then introduced, with China's *Made in China 2025* initiative (Wübbeke et al., 2016), Singapore's *Research Innovation Enterprise 2020 Plan* (National Research Foundation, 2016), and South Korea's *Innovation in Manufacturing 3.0* (Kang et al., 2016). Lastly, Italy launched its *Piano Industria 4.0* (MISE, 2017) and Brazil introduced its plan *Industrial Inovação, Manufatura Avançada e o Futuro da Indústria* (ABDI, 2017). More recently, many more initiatives aiming to spread the Industry 4.0 concept and promote Industry 4.0 technology adoption by local firms have been launched in both developed and developing countries. Alongside these industrial plans, research programs [e.g., *Factory of the Future* (European Commission, 2016)] and public-private partnerships [e.g., *Industrial Internet Consortium* (Evans and Annunziata, 2012)] have also been launched.

Although different in terms of the types of actions and investments undertaken, these government-developed plans are shaped by the needs of industries in their respective countries and reflect local economic conditions, current infrastructure, firm characteristics, and social and cultural norms. Nevertheless, it is possible to identify common characteristics of these industrial plans, including tendencies to undertake awareness-raising activities, create economic infrastructure, deliver training programs, and promote partnership development. Equally, actions specifically addressing businesses are commonly present, including incentives for investment in technology (hyper-amortization and super-amortization) and for the development of intangible resources and training facilities (e.g., tax relief for activities considered essential to the development of the firm), the provision of financial resources, and support for the development of "made in" initiatives. Jain and Ajmera (2020) state that government facilities are major enablers of Industry 4.0 adoption. Furthermore, a study by MISE (2018) shows that greater openness to Industry 4.0 leads firms to adopt more incentives. We thus propose the following research hypothesis:

H4: Greater openness toward Industry 4.0 positively affects the extent of incentive adoption.

Additionally, industrial plans show that governments worldwide have implemented a number of incentive programs to improve the perceived performance of Industry 4.0 technologies (Kagermann et al., 2013; MISE, 2018). Therefore, we propose the following research hypothesis:

H5: The adoption of incentives leads to the perception of improved performance.

The literature (e.g., Frank et al., 2016; MISE, 2018) also highlights how different business plans exploit several incentives to reduce the perceived extent of barriers. This study thus proposes that the degree to which barriers are perceived affects the use of incentives; however, since the types of barriers vary, it is conceivable they have different effects on the incentive uptake degree. As such, we propose the following research hypotheses:

H6a: The perception of higher barriers related to knowledge issues leads to a greater degree of incentive adoption.

H6b: The perception of higher barriers related to economic and financial issues leads to a greater degree of incentive adoption.

H6c: The perception of higher barriers related to cultural issues leads to a greater degree of incentive adoption.

H6d: The perception of higher barriers related to system conditions leads to a greater degree of incentive adoption.

2.6. Research hypotheses model

Based on the described theoretical background and the research hypotheses posited in the previous sections, we develop a model that investigates the relationship between the openness to Industry 4.0 and performance with different mediators (Fig. 2).

3. Methodology

As shown in Fig. 3, the paper uses a mixed-methods methodological approach combining elements of qualitative and quantitative research methods. This approach presents an excellent opportunity to advance the literature by providing a deeper understanding of a complex phenomenon. It also allows to address an exploratory and a confirmatory issue within the same study, along with a better methodological triangulation (Venkatesh et al., 2013).

Fig. 3 shows an overview of the steps used in this study. The theoretical background allows us to identify the concept of openness toward Industry 4.0, performance, barriers, and incentives. The first step – qualitative analysis – allows to validate and integrate the theoretical background, through semi-structured in-depth interviews with academics, entrepreneurs, and policymakers possessing solid experience in Industry 4.0, as well as multiple case studies. The second step – quantitative analysis – allows to test research hypotheses, the paper uses survey data from a sample of manufacturing units. The following subsections present the methods used in more detail.

3.1. Qualitative analysis

Kamble et al. (2018), Raj et al. (2020), and Stentoft et al. (2020) highlight that the performance of businesses after adopting Industry 4.0 technologies and the barriers to adoption remain largely unexplored. This gap shows the need to validate and integrate the theoretical background using our approach.

3.1.1. Semi-structured in-depth interviews

Semi-structured in-depth interviews with experts allow for data to be collected systemically while also ensuring that new and unexpected information can be included (Yin, 2009). The participants in these semi-structured interviews are leading figures within Industry 4.0 public-private partnerships, trade associations, applied research centers, technology transfers or trainers actively helping firms through the Industry 4.0 transition (Table 2). These institutions are either located in or collaborate with relevant actors located in Piedmont (Northern Italy).

The semi-structured in-depth interviews were carried out with the representatives (i.e., presidents, CEOs, managers, consultants) of organizations promoting business development in the manufacturing sector. The involved organizations facilitate networks between business, research, finance, and training at the regional and interregional levels for the growth and economic and industrial development of the sector. Among the involved experts there are organizations representing and providing financial support to firms (E1, E5, E8 in Table 1); organizations creating relationships with research centers (E2, E3, E6 in Table 1); organizations creating networks for innovation (E4 in Table 1); organizations developing the sector's supply chain (E7 in Table 1); and research centers developing innovation 4.0 and providing strategic support to businesses (E9 in Table 1). The firms include more than 400,000 SMEs, while the other organizations provide support to more than 400 enterprises. All the organizations involved—in parallel with the development of business relationships, research, and finance—directly or indirectly carry out training in 4.0 upskilling and reskilling.

The interviews took place in January 2019 via Skype, lasted for 60 min each, and were recorded and transcribed. The authors carried out the interviews, following a semi-structured guide informed by the themes arising from the literature review. Some questions that were

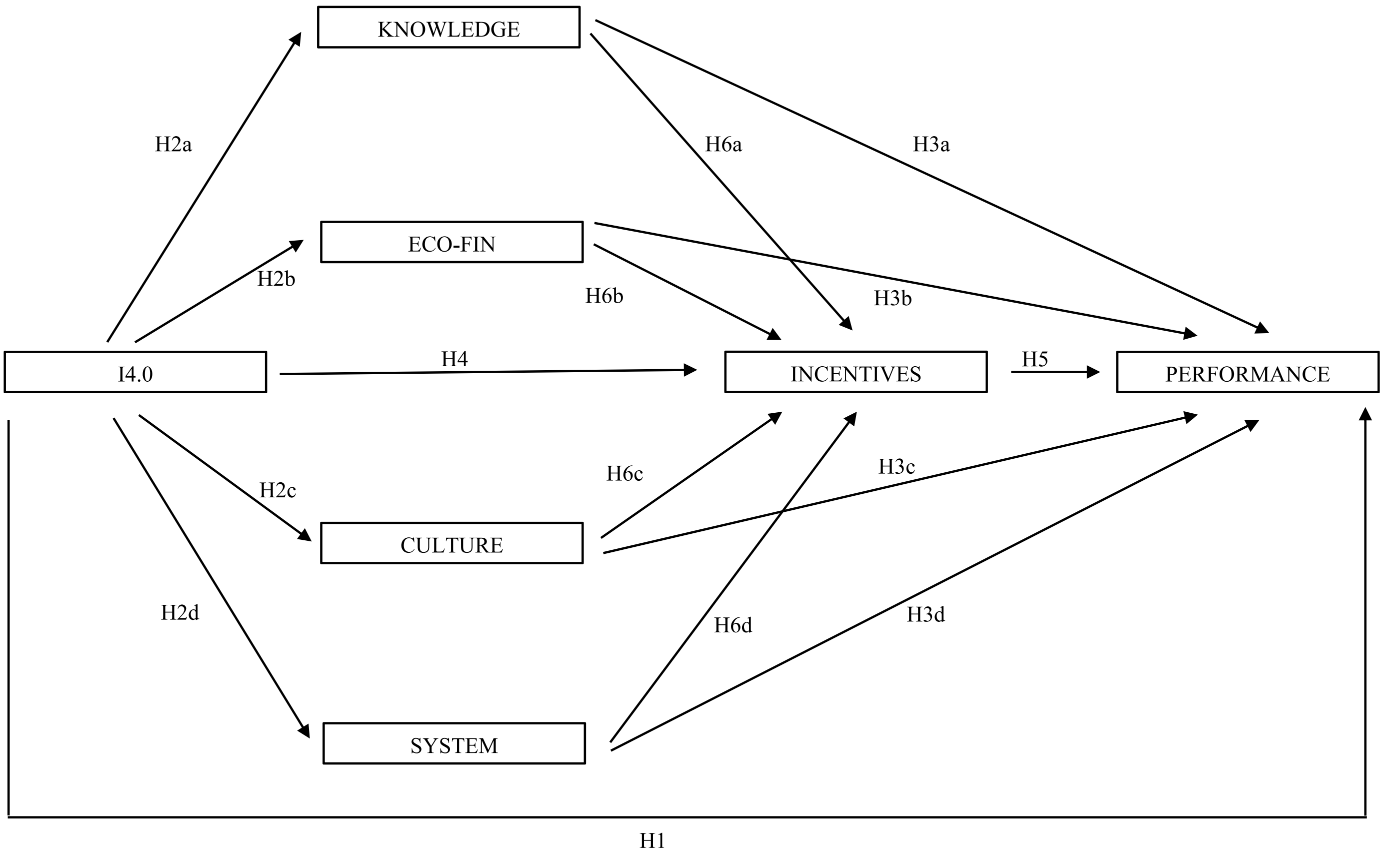

Fig. 2. Research hypotheses model.

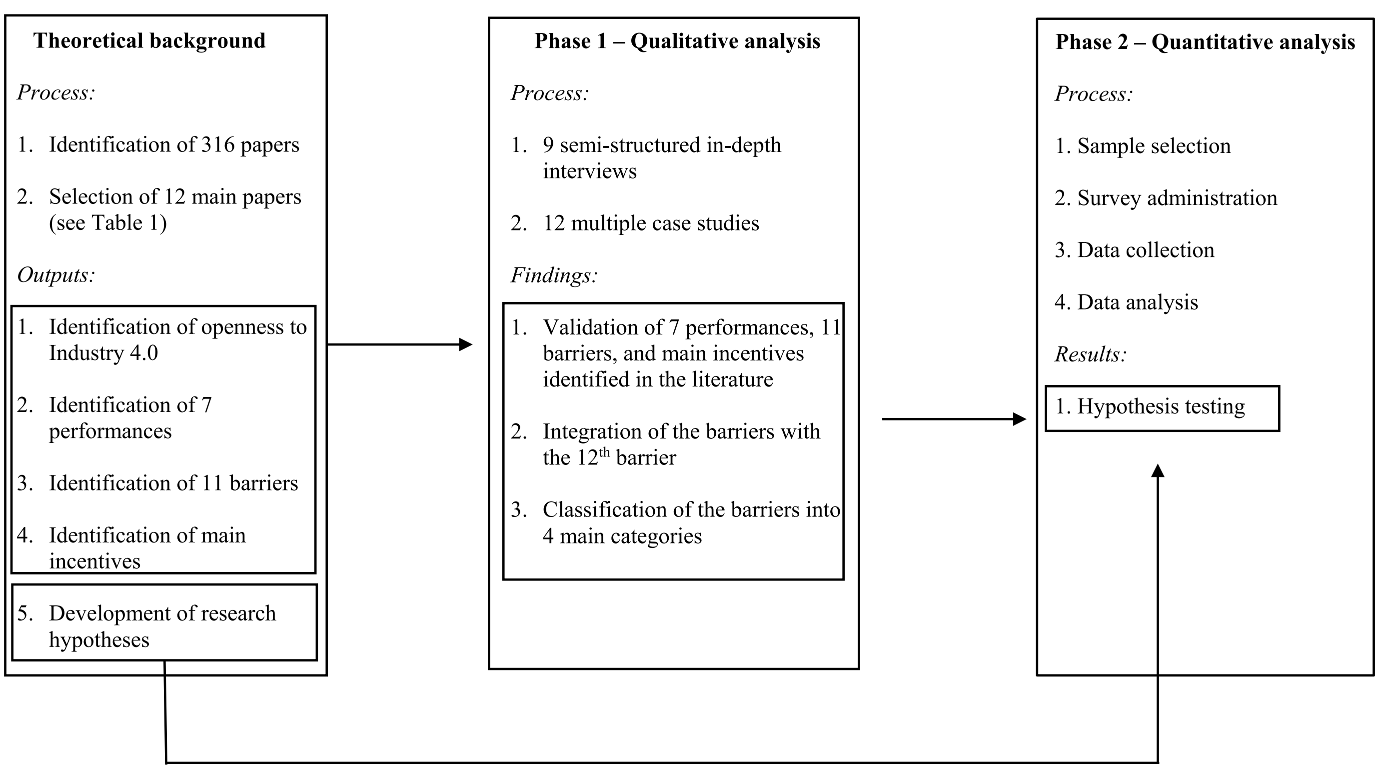

Fig. 3. Methodological steps.

Table 2
Profiles of interviewed experts.

Interviewed experts (E)	Institutional association	Region
E1	SME association	Piedmont, Northern Italy
E2	Technological organization	Piedmont, Northern Italy
E3	Technological organization	Piedmont, Northern Italy
E4	SME association	Piedmont, Northern Italy
E5	Local administration	Piedmont, Northern Italy
E6	Foundation	Piedmont, Northern Italy
E7	Technological organization	Abruzzo, Central Italy
E8	Competence center	Piedmont, Northern Italy
E9	Consultant in research center	Piedmont, Northern Italy

Table 3
Semi-structured interview guide for institutions.

1. Please provide a description of your institution (size, field, kinds of firms with which you collaborate)
2. Please describe the current degree of Industry 4.0 technology adoption by firms with which you work
3. In your opinion, what is the relevance of the following 10 new digital 4.0 technologies?
4. In your opinion, what are the main Industry 4.0 opportunities for firms?
5. In your opinion, what are the main barriers to Industry 4.0 technology implementation faced by firms?
6. In your opinion, what are the main incentives to Industry 4.0 technology adoption for firms?

typically included are reported in Table 3.

The study adopts an interpretive methodology to identify themes emerging from the data in three phases. First, the interview transcripts are compared, the experiences of the interviewees are analyzed, and primary themes are identified. Second, a categorical aggregation is carried out and emerging patterns are identified. Third, the data are revisited to search for relationships between the literature review results and the different concepts emerging from the semi-structured interviews (§5.1).

Respondents have been anonymized to ensure confidentiality and increase result reliability.

3.1.2. Multiple case studies

The multiple case studies consist of in-depth semi-structured interviews on a cross-sector sample of firms (Table 4).

The multiple case studies consider 12 firms belonging to manufacturing sector, distinguished by their technology levels: low technology, medium-low technology, medium-high technology, and high technology industry. For each sector, there are three analyzed firms. The interviewed firms have been mainly conducted with SMEs and, in most cases, implementing Industry 4.0 through the application of CPS and specific 4.0 technologies. In a few cases only one technology is implemented. However, in most cases, the technologies are adopted in the production and design phases and, in one case, they are adopted in all the value chain phases. Most firms adopt Industry 4.0 for internal use, while a few companies produce 4.0 technologies for the market. In the majority of cases, the respondents are the firms' owners.

These semi-structured interviews are combined with additional materials, such as internal reports and web-sites (Eisenhardt and Graebner, 2007).

Firms are selected for inclusion in this sample following the Eurostat (2018) classification of manufacturing industries into categories based on R&D intensities (i.e., low-technology, medium-low-technology,

Table 4
Profiles of the multiple case studies participants.

Multiple case study (CS) participants	CS1	CS2	CS3	CS4	CS5	CS6	CS7	CS8	CS9	CS10	CS11	CS12
Industry	Low-technology industry	Low-technology industry	Low-technology industry	Medium-low-technology industry	Medium-low-technology industry	Medium-low-technology industry	Medium-high-technology industry	Medium-high-technology industry	Medium-high technology industry	High-technology industry	High-technology industry	High-technology industry
Size	Small	SME	Startup	Medium	Large	Medium	Medium	Medium	Medium	Small	Large	Small
Industry 4.0 technology adopted	CPS; cloud; internet of things; cyber security	Advanced manufacturing	CPS	CPS; cloud; internet of things; cyber security	CPS; cloud; internet of things; cyber security	Cobots	Virtual reality; augmented reality	Virtual reality; augmented reality	CPS	Additive manufacturing	All Industry 4.0 technologies	Advanced manufacturing
Current/ potential application areas of Industry 4.0 technologies	Production	Production	Distribution	Production and distribution	Production and distribution	Production	Design and marketing	Design and marketing	Production	Production	All areas	Production
User or producer of Industry 4.0 technologies	User and producer	User	User	User and producer	User and producer	User	User	User	User	User	User and producer	User
Informant	Owner	Owner	Founder	Owner	Owner	Owner	Owner	Owner	Owner	Founder	Innovation and Production Director	Owner

medium-high-technology, and high-technology industries). The sampling criteria are based on an expectation that the more technology intensive the industries are, the more they are ready to use (or indeed are more likely to already use) Industry 4.0 technologies (Dachs et al., 2019).

The multiple cases studies were analyzed by interviews held in January 2019 via Skype. These lasted for 120 min and were recorded and transcribed. The authors carried out the multiple case studies following a semi-structured guide informed by the themes arising from the literature review. The typical questions included are displayed in Table 5.

At this point, this study adopts (for the interviews) an interpretive methodology to identify the themes emerging from the data in three phases. First, the interviews transcripts are compared, the experiences of the interviewees from the multiple case studies analyzed, and the primary themes identifid. Second, a categorical aggregation is carried out and emerging patterns are identified. Finally, the data are revisited to identify relationships between the literature review results and the different concepts emerging from the semi-structured interviews.

The design of the multiple case studies adheres to the recommendations of Eisenhardt (1991), Voss et al., (2002), and Yin (2009) regarding construct validity, internal and external validity, and reliability. Construct validity is achieved by choosing measurement standards that capture the primary features of the constructs under examination (Eisenhardt, 1991) – that is, the performance, barriers, and incentives identified through the literature review (Kiel et al., 2017a). The reconstruction of analyzed papers, both in terms of quality and quantity, guarantees analytical and procedural rigor (Strozzi et al., 2017; Fatorachian and Kazemi, 2021). External validity – that is, the generalizability of the results (Voss et al., 2002) – is reached by carrying out nine interviews on a heterogeneous sample of firms, since conducting multiple interviews improves the validity and utility of results (Eisenhardt and Graebner, 2007; Yin, 2009). Internal validity – that is, the ability of the evidence to support the presence of causal relationships (Edmondson and Mcmanus, 2007; Yin, 2009) – is attained through the semi-structured interviews with managers familiar with the implementation of Industry 4.0 technologies in their firms. Further, in the process of the multiple case studies, the respondents have been granted anonymity.

The size of the qualitative sample is selected based on two factors. The first one is that the extant qualitative studies on the topic have adopted similar sample sizes (Horváth and Szabó, 2019; Moeuf et al., 2020). The second one is determined on the basis of theoretical saturation (Denzin and Lincoln, 1994).

3.2. Quantitative analysis

The quantitative analysis tests the relationship between openness to Industry 4.0 and performance, as driven by barriers and incentives. The following sections present the sample and measures used, the selected variables, and the parallel-serial multiple mediation model.

Table 5
Semi-structured in-depth interview guide for the multiple case studies.

1. Please provide a description of your firm (size, age, products, markets, production methods, suppliers, customers)
2. Please describe your firm's degree of Industry 4.0 adoption
3. What is the relevance of the following 10 new digital 4.0 technologies for your firm and which of the technologies do you currently use?
4. What are the main opportunities presented by Industry 4.0?
5. What are the main barriers encountered to implementing Industry 4.0 technologies?
6. What are the incentives for adopting Industry 4.0 technologies?

3.2.1. Sampling and measurement

The hypotheses are tested using a publicly available secondary dataset entitled *Congiuntura Industriale in Piemonte*, for which data is collected every year by Unioncamere Piemonte (2019).[1] The data for the year 2019 are obtained from a representative sample of 1732 local manufacturing units in Piedmont (Northern Italy) which have at least two employees working in prominent economic sectors of the manufacturing industry: food; textiles, clothing, and footwear; wood and furniture; chemicals, petroleum, and plastics; metals; electronics and mechanical goods; transport; or other manufacturing industries) across different size classes (micro, small, medium, and large enterprises).

Before sharing the data file, Unioncamere Piemonte deleted cases with missing data and validated the dataset. Not all units in the dataset adopted Industry 4.0; However, in this study, only local units that adopted one or more Industry 4.0-enabling technologies were analyzed. This produced a sample of 500 local manufacturing units (28.9% of the original 1732 local units). This percentage is above the national average of Italian firms in the industrial and service sectors, for which the equivalent percentage figure recorded in 2017 was 8.4%, and above the sample of large 'Made in Italy' companies (which had an annual turnover of over 1000,000€) in Northern Italy, which recorded 19% (MISE, 2018). This region is particularly noteworthy, as it is highly committed to manufacturing (ISTAT, 2018), with a high degree of innovation as part of Industry 4.0 (MISE, 2018).

This large-scale industrial survey provides data for analysis of the manufacturing sector's performance and dedicates a specific section to Industry 4.0. The survey, which was conducted by e-mail with the input of the managers of local manufacturing units between January and April 2019, was implemented and validated by Unioncamere Piemonte.

The survey contains information on local manufacturing units' demographic characteristics, their number of employees, and their sector of operation. The thematic section dedicated to Industry 4.0 is composed of seven main questions relating to the following focuses.

(1) Industry 4.0 adoption (dummy coding).
(2) Industry 4.0 technologies adopted out of a list of 10 pillars (advanced manufacturing, augmented reality, the internet of things, big data, cloud computing, cyber security, additive manufacturing, simulations, horizontal and vertical integration, and *other technologies*). Each local unit can adopt one or more of these pillars.
(3) Stages of the value chain from a list of the six phases of the value chain in which each pillar can be employed (production, R&D, warehouse logistics, purchasing, sales, and administration).
(4) Future investments (i.e., the willingness to invest in Industry 4.0 over the next three years) (dummy coding).
(5) Perceived opportunities from a list of seven opportunities associated with the adoption of Industry 4.0, as identified in the theoretical background (reduced time from prototype to production, greater productivity through shorter set-up times, the reduction of errors and machine downtimes, better quality and less waste, greater product competitiveness due to greater product functionality, improved human resources productivity). The *other opportunities* category was added after the validation of the theoretical framework through in-depth interviews with experts.
(6) Perceived barriers from a list of twelfth barriers that hinder the adoption of Industry 4.0 technologies, as identified in the theoretical background (little information on the potential offered by Industry 4.0 technologies, insufficient knowhow or lack of internal skills, few skills available in the labor market, insufficient financial resources within the firm, a lack of external financing,

[1] Unioncamere Piemonte is the regional chamber of commerce, industry, crafts, and agriculture union for the Piedmont region (Northern Italy). The chamber system is made up of about 500,000 firms from a variety of economic sectors. In total, they represent more than 1,500,000 employees

insufficient broadband connections, legal uncertainties, problems in relationships with universities and research centers, a lack of clear standards, organizational resistance, the firm's business sector not being seen to need investment in Industry 4.0, a lack of information on public facilities to support investment in Industry 4.0 technologies). The *lack of information on public facilities to support investment in Industry 4.0 technologies* and *other barriers* categories were added after the validation of the theoretical framework through in-depth interviews with experts.

(7) Business plan incentives from a list of nine incentives (MISE, 2017) that firms can use to adopt and/or implement Industry 4.0 technologies (super-amortization, hyper-amortization, contributions for the purchase of capital goods, guarantee funds, R&D tax credits, a "Made in Italy" extraordinary plan, training tax credit 4.0, intangible capital funds, and *other measures*). Each firm can activate one or more incentives without the need to participate in tenders.

3.2.2. *Variable selection*

The paper empirically analyzes the relationship between the degree of openness to the ten pillars of Industry 4.0 and firms' performance, as driven by perceived barriers and incentives. Openness is reflected by the independent variable I4.0, which is based on the empirical analysis of Büchi et al. (2020a), and the dependent variable is PERFORMANCE.

3.2.2.1. Dependent variables. The performance variable (PERFORMANCE) sums the seven opportunity variables listed in Section 2.3, where each is a dummy variable coded as 1 to indicate perceived opportunities or 0 otherwise. The seven dummies are then summed to obtain an indicator of the breadth of opportunities, ranging from 0 – indicating that no opportunities are perceived to derive from the adoption of Industry 4.0 technologies – to 7, where opportunities are seen to derive from all aspects.

3.2.2.2. Independent variables. The level of openness to Industry 4.0 is assessed by the breadth of 4.0 technologies identified in the Industry 4.0 literature (Vogel-Heuser and Hess, 2016; Büchi et al., 2020a).

The value of I4.0 is the sum of the ten pillars of Industry 4.0 technologies, where each is a dummy variable, coded as 1 if the technology is implemented and 0 otherwise. The ten dummies are then summed to obtain an indicator of Industry 4.0 implementation, ranging from 1 – if only one pillar has been adopted – to 10, if all pillars have been implemented. Although the variable is a relatively simple construct, it has a high degree of internal consistency, producing a Cronbach's alpha coefficient of 0.8.

3.2.2.3. Intermediary variables. The Industry 4.0 literature (see Section 2.4) shows that there are distinct types of barriers (i.e., those relating to knowledge, economic and financial issues, cultural issues, and system conditions) that can hinder the adoption of Industry 4.0, and several incentives that promote adoption. Reflecting this, we employ four barrier types: KNOWLEDGE, ECO-FIN, CULTURE, and SYSTEM.

The KNOWLEDGE variable is made up of two barriers: insufficient knowhow within companies and few skills in the labor market. Each variable is a dummy variable, coded as 1 if the barrier is perceived, and 0 otherwise. The two dummies are then summed to obtain a knowledge barrier indicator ranging from 0, if no knowledge barriers are perceived, to 2, if both knowledge barriers are perceived. Although the variable is a relatively simple construct, it has a high degree of internal consistency, producing a Cronbach's alpha coefficient of 0.7.

The ECO-FIN variable is made up of two barriers: insufficient financial resources within the firm and scarcity of external financing. Each variable is a dummy variable, coded as 1 if the barrier is perceived, and 0 otherwise. The two dummies are then summed to obtain an indicator of economic and financial barriers, ranging from 0, if no economic and financial barriers are perceived, to 2, if both economic and financial barriers are perceived. Although the variable is a relatively simple construct, it has a high degree of internal consistency, producing a Cronbach's alpha coefficient of 0.9.

The CULTURE variable is made up of three barriers (little information on the potential offered by Industry 4.0 technologies, a perception that the business sector of operation does not need investment in Industry 4.0, and organizational resistance). Each variable is a dummy variable, coded as 1 if the barrier is not perceived, and 0 otherwise. The four dummies are then summed to obtain an indicator of cultural barriers, ranging from 0, if no cultural barriers are perceived, to 4, if all cultural barriers are perceived. Although the variable is a relatively simple construct, it has a high degree of internal consistency, producing a Cronbach's alpha coefficient of 0.7.

The SYSTEM variable is made up of four barriers: legal uncertainties, insufficient economic infrastructure, difficulties developing partnerships with universities and research centers, and a lack of clear standards). Each variable is a dummy variable, coded as 1 if the barrier is perceived, and 0 otherwise. The four dummies are then summed to obtain an indicator of system condition barriers, ranging from 0, if no system condition barriers are perceived, to 4, if all system condition barriers are perceived. Although the variable is a relatively simple construct, it has a high degree of internal consistency, producing a Cronbach's alpha coefficient of 0.7.

The INCENTIVES variable is a combination of ten incentives. Each variable is a dummy variable, coded as 1 if the incentive is utilized, and 0 otherwise. The ten dummies are then summed to obtain an indicator of incentives, ranging from 1, if only one incentive is used, to 10, if all incentives are used. Although the variable is a relatively simple construct, it has a high degree of internal consistency, producing a Cronbach's alpha coefficient of 0.7.

3.2.3. *Parallel-serial multiple mediation model*

The hypotheses developed in Section 2.6 are evaluated through an OLS regression-based path analysis using the parallel-serial multiple mediation model – a method that has recently become more popular with researchers (Moyer-Guse et al., 2011; Katz et al., 2012; Valdesolo and Graham, 2014; Richard and Purnell, 2017). The sample size is slightly above the average for parallel-serial multiple mediation model studies (Katz et al., 2012; Moyer-Guse, Chung, and Jain, 2011; Richard and Purnell, 2017; Valdesolo and Graham, 2014), which supports the reliability of the obtained results.

The research hypotheses propose the existence of a relationship between openness to Industry 4.0 (I4.0) and performance (PERFORMANCE) affected by five intermediary factors – four concerning the different types of barriers (KNOWLEDGE, ECO-FIN, CULTURE, and SYSTEM) and one concerning incentives (INCENTIVES). The model blends serial and parallel mediation processes, where parallel mediation considers the four types of barriers that influence the serial intermediary incentives.

Estimation is undertaken via an OLS regression-based path analysis, conducted using a PROCESS macro v.3.5 for SPSS (Hayes, 2020). The direct and indirect effects of I4.0 are estimated using six equations: one for each of the five mediators and one for performance. The model was tested using the bootstrapping method on samples of 5000 units.

4. Findings and results

4.1. *Qualitative findings*

The results of the qualitative analysis are reported below, following the same division into four main topics used in the theoretical background section: openness to Industry 4.0, performance, barriers, and incentives. The analysis of the text of the semi-structured in-depth interviews with experts and the respondents of the multiple case studies allowed us to identify the recurring keywords and phrases and identify main categories. These results are summarized in Table 6 and the main concepts are then developed in the following sections.

4.1.1. Openness toward Industry 4.0

The experts identified strong growth in the adoption of Industry 4.0 by firms. Similar observations were made by the respondents to the case studies.

As far as operation technologies are concerned, the highest growth is linked to additive manufacturing, followed by advanced manufacturing, which have been mainly implemented through the use of collaborative robots. Regarding information technologies, industrial analytics and cloud computing are the most developed technologies.

The results of the interviews and case studies show that the concept of openness toward Industry 4.0 is linked to the breadth of the adopted 4.0 technologies, considering that both the type of technology (e.g., advanced manufacturing, augmented reality) and the combinations between technologies are relevant. Therefore, the theoretical background of the openness toward Industry 4.0 has been validated by the qualitative analysis.

4.1.2. Performance

The experts and respondents observed that firms pay particular attention to their performance related to production flexibility and greater output capacity. Concerning this aspect, the experts of the organizations representing firms (E1, E5, and E8) pointed out that the performance that allows them to respond in a timely manner to demand imbalances and the execution of customized products are perceived as more important than others. In particular, this perception is that of SMEs, in that without 4.0 solutions there would be difficulties in modifying volumes and product variety quickly and with low costs. In case studies as well, the entrepreneurs, CEOs, and startup founders emphasized above all the importance of the performance indicators related to flexibility, production capacity, and better product perception by customers. For example, interviewee CS11 affirmed that: "Since we have adopted Industry 4.0, we have achieved a clear improvement in production capacity thanks to the support of 3D printing in mass production. The latter has been particularly useful in responding to our customers' requests for customized production."

According to expert E8: "Industry 4.0 makes possible to remotely manage relations with customers […], to empower supply chains, new forms of conviviality for the promotion of products and spaces for the valorization of firms, partly supporting the crisis of distrust in Made in Italy products." A similar answer was given by interviewee CS7: "Since we have created our products with augmented reality, our customers are more satisfied and also help us to develop products for other customers […]."

Expert E9 pointed out that: "Entrepreneurs ask us for technologies that allow to reduce maintenance costs, to increase the volumes produced, and to achieve significant cost savings […] in order to improve the economies of scale, scope and networking."

All experts and entrepreneurs agree that a fundamental role is played by the 4.0 skills that can facilitate the implementation of Industry 4.0. For instance, expert E6 stated that: "Participants in our lessons, once they have joined the company, empower the learning ability to the other members thanks to a greater capacity for collaboration and exchange on the skills and abilities learned."

Furthermore, the experts emphasized the importance of simulation in prototyping. In this regard, expert E7 reported: "Since manufacturing companies have adopted simulation technologies, the speed of prototyping has largely increased, while production waste have been reduced." This statement also underscores the relevance of Industry 4.0 in reducing production waste, alongside the ability to control energy consumption. Expert E9 also highlighted this last point: "[…] In particular, the Internet of Things allows greater control over energy consumption and intervening in real time limiting waste."

The recurring keywords/phrases in the interviews show that most

Table 6
Qualitative findings.

Topic	Categories	Recurring keywords/phrases
Openness toward Industry 4.0	Breadth of 4.0 technology adoption	- Types of technologies - Combination of different technologies
Performance	P1 – Production flexibility	- Mass customization - Mass personalization - Real-time answer to market changes - Adaptability to market requirements - Satisfaction of customers' needs - Increased variety
	P2 – Speed of serial prototypes	- Reduced time in the design phase due to simulation - Reduced waste of material due to additive manufacturing
	P3 – Greater output capacity	- Use of different production models in varying combinations: mass production + mass customization + mass personalization - Higher full capacity
	P4 – Reduced set-up costs, fewer errors, and shorter machine downtimes	- Optimization - Waste reduction due to virtual reality and simulation - Increased scale and scope economies - Predictive maintenance - Increased resistance to production failures - Reduced lead time - Faster time to market - Energy saving
	P5 – Higher product quality and fewer rejected products	- Energy efficiency - Sustainability - Circular economy
	P6 – Customers' improved opinion of products	- Co-design - Co-creation - Tailored products - Interconnected products through Internet of Things
	P7 – Improved productivity of human resources	- Work-life balance - Smart working - Work flexibility - Improved ergonomics of working devices - Increased internal and external communication - Training courses through virtual/augmented reality - Greater inclusiveness
Barriers	C1 – Knowledge	- Insufficient knowhow within companies (B2) - Few skills in the labor market (B3) - Little information on public facilities to support investments in Industry 4.0 (B12)
	C2 – Eco-fin	- Insufficient financial resources within the firm (B4) - Scarcity of external financing (B5)
	C3 – Culture	- Inadequate information on the potential offered by Industry 4.0 technologies (B1) - Perception that the business sector of operation does not require investment in Industry 4.0 (B11) - Organizational resistance (B10)
	C4 – System	- Legal uncertainties (B7) - Insufficient economic infrastructure (B6)

(*continued on next page*)

Table 6 (*continued*)

Topic	Categories	Recurring keywords/phrases
Incentives	Breadth of incentives adoption	- Difficulties developing partnerships with universities and research centers (B8) - Lack of clear standards (B9) - Investment in technology - Development of intangible resources and training facilities - Provision of financial resources - Support for the development of "made in" initiatives

experts and respondents perceive all seven performance categories identified in the theoretical background section. Therefore, the theoretical background of performance has been validated by the qualitative analysis.

Additionally, in most cases, the performance types are jointly perceived as combinations of several performances. The experts thus recommend to measure the perception of performance in terms of breadth, that is, as a perception of one or more performances.

4.1.3. Barriers

The experts and respondents highlighted that there are four main barriers, namely those related to knowledge issues, economic-financial resources, cultural aspects, and system conditions.

The knowledge issues seem stronger for highly innovative sectors (e.g., automotive, aerospace). In this regard, expert E9 stated: "Firms describe accurately their problems […] and they know that 4.0 technologies can help them […]. However, it is necessary not only to adopt technologies but also to provide them with strategic support for the new management of the firms."

Additionally, expert E1 highlighted: "The use of the term Industry 4.0 is not clear. In particular, small firms often confuse individual 4.0 technologies with the opportunities that arise from the realization of a 4.0 environment." The experts also pointed out that these technologies can only be implemented through the interconnection of smart factory, which that requires ad hoc infrastructure. However, they considered that most SMEs adopt a limited number of technologies and do not often create an integrated 4.0 environment. For example, respondent E8 stated: "Applying Industry 4.0 is not only buying new technologies, but it is the result of a total reconfiguration of the company," while respondent CS10 explained: "The application of 4.0 technologies is complicated and requires a long procedure."

The experts also identified problems related to a lack of knowledge on the opportunities of Industry 4.0. The difficulties also concern the acquisition of skills, knowledge, and abilities through the internal training of human capital and the use of suitable professional profiles in the labor market. As reported by expert E9, "Industry 4.0 changes the competencies of both white collars and blue collars. The latter, in particular, often have less specific knowledge and technical skills in routine tasks, while increasing the digital skills that allow them more control over more production phases, more machines, and more functions".

Furthermore, experts E3 and E6 agreed that: "Employees must have a specialization on their specific tasks, but at the same time, they must have transversal knowledge so that they can collaborate in teams and be more adaptable to the various tasks […]. The development of this competence can only be partially covered by reskilling." Expert E2 added that: "The most required skills in the labor market are related to hard and soft digital skills, security, and problem solving activities." In this regard the respondent CS11 adds that: "Since our firm has become smart, we are having problems identifying qualified Industry 4.0 workforce," and respondent CS4 emphasized: "The employees were incredulous […] and displays and iPad could support them in the quality control of products. However, understanding this change was not easy. […] The tasks were very different from the previous ones."

The experts pointed out that investing in Industry 4.0 requires substantial capital that is not always available to firms and might be difficult to access externally. Concerning this aspect, expert E1 stated: "In addition to the difficulties linked to the shortage of human resources, there has been a serious liquidity crisis in Italian firms." Expert E4 and E5 agreed and stressed that: "[As organizations] in this direction, we have realized several vouchers and activities in favor of the acquisition of connectivity and training of human resources." CS10 added: "The customer couldn't believe it: A small 3D printer had made his dreams come true! […] However, the result was not easy if we think that we started with few resources (financial)."

The nine experts all agreed that the main barriers to Industry 4.0 are related to the lack of transformation of organizational processes and cultural resistance. This resistance is partly due to the presence of smaller family businesses that put the interests of the family before those of the business in Italy. The various interviewees agreed that entrepreneurs are inclined to question to status quo: "It has always been done so… why we should change?" Expert E1 insisted that: "The greatest difficulty for entrepreneurs is the transformation of a 4.0 behavior, that is, the willingness to promote behaviors that develop new ways of doing business and transform business models."

In some cases, entrepreneurs were even convinced that the industry to which their firms belong to does not need to adopt Industry 4.0. These problems are well highlighted by expert E4: "When I contact firms, many entrepreneurs answer me: […] among the many troubles, why should I take care of Industry 4.0? Making them understand the opportunities of Industry 4.0 is not easy […]." Expert E4 also pointed out that: "It is not only a problem of culture, but also of fear that the changes undertaken will not bring good profit. Very often those in charge of the firm answer me that their sector does not require technological investment. […]."

Expert E5 emphasized that: "The application of Industry 4.0 can only be implemented through an interconnection of the enterprise with the supply and distribution chain and therefore requires a strong use of technical infrastructure for the transmission of information and legislation that covers the new digital transformations and promotes the implementation of international cooperation." Expert E3 also pointed out this problem and emphasized further difficulties: "At present, many entrepreneurs complain about a lack of unambiguous standards."

Based on the opinions of the experts and interviewees, the implementation of Industry 4.0 in enterprises must be accompanied by the creation of partnerships and networks between enterprises for the development of innovation ecosystems. Expert E7, in fact, reported: "The creation of long supply chains and the aggregation of firms through a bottom-up approach is necessary to better respond to different market needs." Additionally, the experts generally underlined the relevance of collaboration and exchanges with universities and research centers, stating, for example: "For a company, creating alliances with research centers and universities becomes fundamental" (E7). Respondent CS1 also reported: "When we wanted to implement Industry 4.0 we didn't know where to start. […] Then we found out, thanks to our representative organizations, who could help us." Respondent CS11 stated: "If we do not have the internal capabilities to understand which 4.0 technologies to apply, our employees know which research centers to contact and which external consultants can help us identifying the right incentives (industrial plan measures)." Raising this issue, one expert noted: "Entrepreneurs come to us to find solutions to their problems […] and are surprised that there are already places dedicated to the development and implementation of 4.0 solutions" (E1).

In conclusion, all experts validate the importance of all barriers identified in the theoretical background section. The qualitative analysis also identifies an additional barrier perceived by most participants but not identified in the literature. This barrier was thus added to the 11 barriers presented in the theoretical background section and classified as B12 – little information on public facilities to support investments in Industry 4.0. B12 reinforces the perception of cultural barriers, which, according to the participants, present sizeable problems.

Additionally, the qualitative analysis results lead to the classification of barriers into the four categories—knowledge issues, economic and financial issues, cultural issues, and system conditions (see Table 6). The barriers considered most influential were cultural, namely B1 (inadequate information on the potential offered by 4.0 technologies), B10 (organizational resistance), B11 (perception that the business sector of operation does not need investment in Industry 4.0) and B12 (little information on public facilities to support investments in Industry 4.0), and economic and financial, that is, B4 (insufficient financial resources within the company) and B5 (scarcity of external financing).

The several categories of barriers (related to knowledge issues, economic-financial aspects, cultural concerns, and system conditions) are perceived in most cases as a sum of several barriers belonging to the same category. This is why the experts recommended to measure the perception of barriers in terms of breadth for each category.

4.1.4. Incentives

The experts and respondents state that different firms have a varied degree of knowledge on industrial plans. All companies are generally aware that the business plan allows them to support the development of Industry 4.0. However, when asked to go into detail about the firms' incentives, they show a heterogeneous knowledge of government incentives. Larger firms and newborn firms have a deep knowledge of industrial plan incentives.

By contrast, the experts and respondents implied that SMEs have a superficial knowledge of government incentives. For instance, expert E4 stated: "[…] The biggest problem is that firms do not know the existence of certain incentives and/or do not know how to access them."

Both experts and respondents agreed that the application of incentives under the Italian Industrial Plan (Impresa 4.0) can facilitate the adoption of Industry 4.0 and identified that the most used incentives are those related to the amortization of investments in technologies and to human capital training. Therefore, the qualitative analysis allows to validate the theoretical background on incentives as well.

Furthermore, in most cases, several incentives are adopted as combinations. Therefore, experts recommend to measure the adoption of incentives in terms of breadth.

4.2. Quantitative results

The results of the multiple parallel-serial model, which considers the relationship between openness to Industry 4.0 (I4.0) and performance (PERFORMANCE), as driven by the direct and indirect effects of five intermediary variables, is shown in Tables 7 and 8.

The first four mediators, linked to the nature of the barriers, do not condition themselves causally – parallel mediations – but their paths condition the incentives – serial mediation.

The model has seven specific indirect effects, four of which pass through only one mediator (a1b1; a2b2; a3b3, and a4b4), and three pass through two mediators (a1d41b4; a2d42b4; and a3d43b4). The sum of these effects produces the total indirect effect. The direct effect of I4.0 is c' and the sum of the direct and indirect effects is the total effect of I4.0 on PERFORMANCE. In this model, the total effect can also be estimated by regressing PERFORMANCE onto I4.0 without any mediators included in the model.

Table 7 shows a significant effect, whilst Table 8 shows that the indirect effects on perceived barriers are in some cases very weak. This suggests that some barriers and incentives might also be independent from openness to Industry 4.0. The results relating to our hypotheses are provided below.

Table 7
Direct effect.

Effect	SE	t	p	LLCI	ULCI
.1478	.0255	5.7884	<0.0001	.0976	.1979

Fig. 4 presents the results of the hypotheses testing and Table 9 provides an overview of the hypotheses supported or those not supported and those accepted or rejected. In total, out of the 15 hypotheses, only hypothesis H6b is rejected and H3c, H3d, H6a, H6c, and H6d are not supported.

H1 proposes that greater openness to Industry 4.0 leads to the perception of better performance. The empirical results show a positive and significant relationship between these two factors (β = 0.148, t = 5.788, $p < 0.001$). Hence, *H1* is accepted.

H2a states that greater openness to Industry 4.0 leads to the perception of higher barriers relating to knowledge issues. The results indicate a positive and significant relationship between these variables (β = 0.051, t = 3.533, $p < 0.001$), which provides evidence to accept *H2a*.

H2b proposes that greater openness to Industry 4.0 leads to the perception of higher barriers relating to economic and financial issues. The empirical results indicate a significant and positive relationship between these factors (β = 0.031, t = 2.338, $p < 0.01$), thus accepting *H2b*.

H2c states that greater openness to Industry 4.0 leads to the perception of higher barriers relating to cultural issues. The results show a positive and significant relationship (β = 0.031, t = 1.761, $p <$ 0.1), thereby providing evidence to accept *H2c*.

H2d proposes that greater openness to Industry 4.0 leads to the perception of higher barriers relating to system conditions. The results show a positive and significant relationship (β = 0.075, t = 5.555, $p < 0.001$). Hence, is find evidence to accept *H2d*.

H3a proposes that greater perceived barriers relating to knowledge issues lead to the perception of improved performance. In this case, the empirical results do not indicate a significant relationship (β = 0.224, t = 2.910, $p < 0.1$). Hence, *H3a* is accepted.

H3b states that greater perceived barriers relating to economic and financial issues lead to the perception of improved performance. The empirical results show a positive and significant relationship (β = 0.223, t = 2.670, $p < 0.1$). Therefore, evidence is found to accept *H3b*.

H3c affirms that greater perceived barriers relating to cultural issues lead to the perception of improved performance. The empirical results indicate no significant relationship (β = 0.073, t = 1.174, $p >$ 0.1); Therefore, *H3c* is not supported.

H3d proposes that greater perceived barriers relating to system conditions lead to the perception of improved performance. The empirical results indicate no significant relationship (β = 0.048, t = 0.599, $p > 0.1$). Hence, *H3d* is not supported.

H4 proposes that greater openness to Industry 4.0 leads to a greater degree of incentives adoption. The empirical analysis shows a positive and significant relationship (β = 0.075, t = 2.273, $p < 0.1$), providing evidence to accept *H4*.

H5 states that a higher number of adopted incentives leads to the perception of improved performance. The empirical analysis shows a positive and significant relationship (β = 0.175, t = 5.057, $p < 0.1$). Therefore, evidence is found to accept *H5*.

H6a considers the perception of higher barriers relating to knowledge issues to lead to a greater degree of incentives adoption. In this case, the empirical results do not indicate the presence of a significant relationship (β = 0.143, t = 1.432, $p > 0.1$). Therefore, *H6a* is not supported.

H6b states that the perception of higher barriers relating to economic and financial issues leads to a greater degree of incentives adoption. The empirical analysis shows a negative and significant relationship (β = -0.266, t = -2.461, $p < 0.1$). Hence, *H6b* is rejected.

H6c proposes that the perception of higher barriers relating to cultural issues leads to a greater degree of incentives adoption. The

Table 8
Indirect effects.

	Effect	BootSE	BootLLCI	BootULCI
TOTAL	.3670	.0125	.0144	.0641
Ind1 I40→KNOWLEDGE→PERFORMANCE	.0113	.0053	.0027	.0234
Ind2 I40→ECO-FIN→ PERFORMANCE	.0069	.0046	.0002	.0179
Ind3 I40→CULTURE→PERFORMANCE	.0023	.0026	-0.0019	.0065
Ind4 I40→SYSTEM→PERFORMANCE	.0036	.0062	-0.0078	.0168
Ind5 I40→INCENTIVES→PERFORMANCE	.0131	.0070	.0002	.0279
Ind6 I40→KNOWLEDGE→INCENTIVES→PERFORMANCE	.0013	.0011	-0.0005	.0038
Ind7 I40→ECO-FIN →INCENTIVES →PERFORMANCE	-0.0014	.0009	-0.0036	-0.0001
Ind8 I40→CULTURE→INCENTIVES→PERFORMANCE	-0.0005	.0006	-.0017	.0005
Ind9 I40→SYSTEM→INCENTIVES→PERFORMANCE	.0001	.0015	-0.0029	.0031

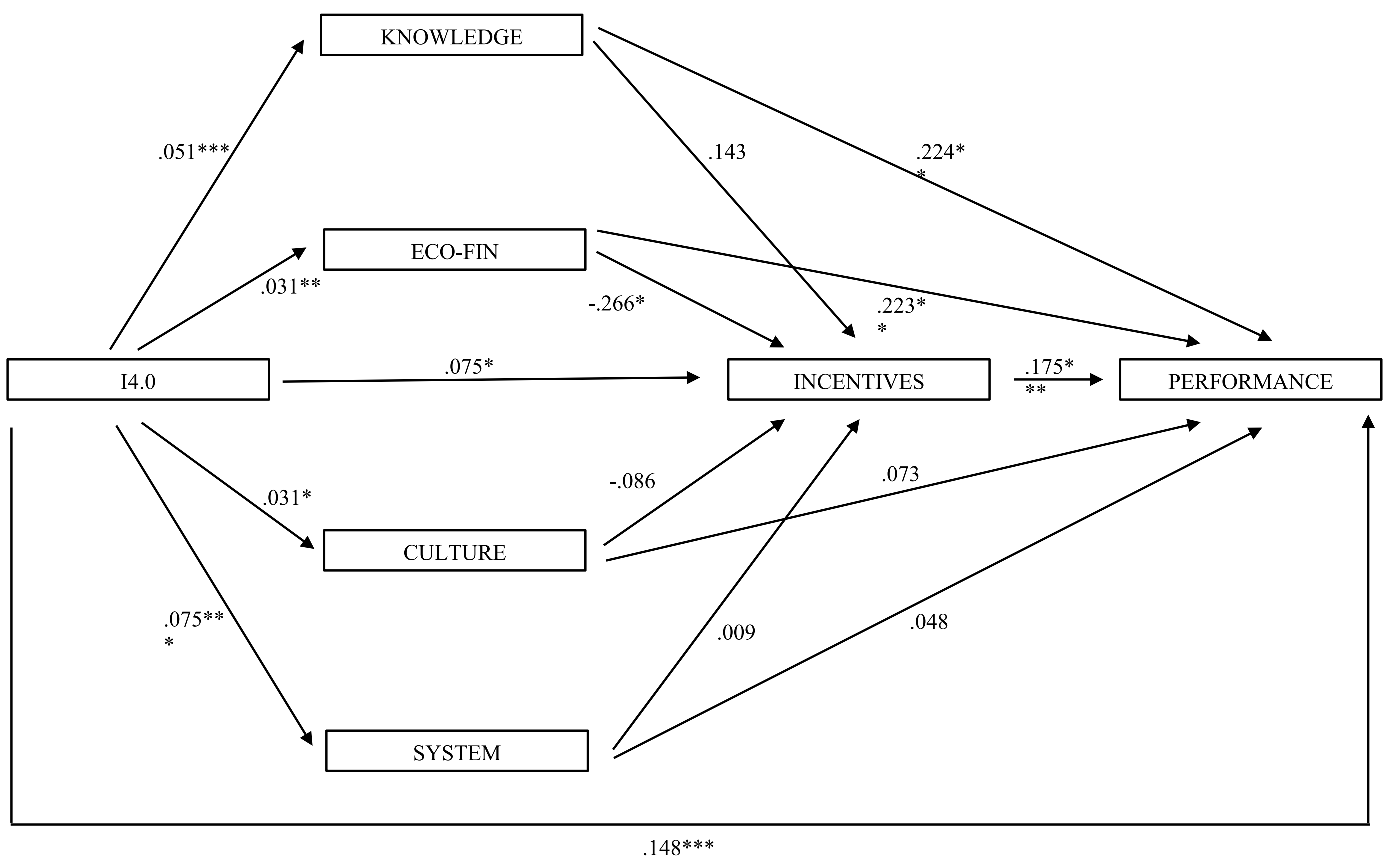

Fig. 4. Results *, **, and *** indicate that the coefficients are statistically significant at the <5%, <1%, and <1% levels, respectively.

empirical results indicate no significant relationship (β = -0.086, t = -1.070, $p > 0.1$); Therefore, *H6c* is not supported.

H6d states that the perception of higher barriers relating to system conditions leads to a greater degree of incentives adoption. The empirical results indicate no significant relationship (β = 0.009, t = 0.086, $p > 0.1$). Thus, *H6d* is not supported.

5. Discussion

5.1. Discussion of qualitative findings

From the analysis of the answers of the experts and interviewees, some reflections confirm and/or apply the management literature.

Larger firms and those belonging to the high-tech sectors are more used to adopt Industry 4.0. The results confirm the empirical results of Dachs et al. (2019). The increased propensity to use enabling technologies by younger firms can be explained by the presence of young employees, with a high propensity for innovation 4.0 and/or with specific digital skills.

The performance factors related to greater production flexibility and greater output capacity clarify that Industry 4.0 allows to combine mass production, mass customization, and mass personalization. This opportunity—combined with the reduction of costs—favors companies with economies of scale, relevant scope, and networking. These results confirm those theoretically highlighted by Büchi et al. (2018).

Human resources 4.0 allows a better implementation of Industry 4.0 in firms. This result is in line with the literature (i.e., Moeuf et al., 2020). The results also show that, if 4.0 resources are available, they can create an environment that stimulates the productivity of the entire organization.

However, there is still a lack of proper recognition of both the term Industry 4.0 and the related opportunities. Additionally, the adopted 4.0 technologies are still limited. This confirms the theoretical results of Vogel-Hesuer and Hess (2016). The results also highlight that the implementation of these technologies takes place in several phases of the supply chain. This confirms the empirical study of Büchi et al. (2020a).

Table 9
Hypothesis testing results.

H	Short description	Outcome	Accepted or rejected	Impact
H1	I40 → Performance	Supported	Accepted	A greater openness toward Industry 4.0 corresponds to a higher perceived performance
H2a	I40 → Knowledge	Supported	Accepted	A greater openness toward Industry 4.0 corresponds to more perceived knowledge barriers
H2b	I40 → Eco-fin	Supported	Accepted	A greater openness toward Industry 4.0 corresponds to perceived economic-financial barriers
H2c	I40 → Culture	Supported	Accepted	A greater openness toward Industry 4.0 corresponds to higher perceived cultural barriers
H2d	I40 → System	Supported	Accepted	A greater openness to Industry 4.0 corresponds to higher perceived system barriers
H3a	Knowledge → Performance	Supported	Accepted	A higher perception of knowledge barriers corresponds to higher perceived performance
H3b	Eco-fin → Performance	Supported	Accepted	A higher perception of economic-financial barriers corresponds to higher perceived performance
H3c	Culture → Performance	Not supported		–
H3d	System → Performance	Not supported		–
H4	I40 → Incentives	Supported	Accepted	A greater openness toward Industry 4.0 corresponds to higher incentives adoption
H5	Incentives → performance	Supported	Accepted	A higher incentive adoption corresponds to higher perceived performances
H6a	Knowledge → Incentives	Not supported		–
H6b	Eco-fin → Incentives	Supported	Rejected	A higher perception of economic-financial barriers does not correspond to a higher incentive adoption
H6c	Culture → Incentives	Not supported		–
H6d	System → Incentives	Not supported		–

The implementation of Industry 4.0 requires large investments that firms do not always have available internally and are not easy to access externally. This confirms the literature as well. From the results of this study, it emerges that the barriers considered most influential are the cultural ones related to: *B1 (inadequate information on the potential offered by 4.0 technologies), B10 (organizational resistance*) and *B11 (perception that the business' sector of operation does not need investment in Industry 4.0)*. To these barriers already identified in the literature, the qualitative analysis conducted identifies an additional one: B12 (*little information on public facilities to support investments in Industry 4.0)*.

The implementation of Industry 4.0 must also be accompanied by the creation of partnerships and networks between firms for the development of innovation ecosystems. However, this aspect is little highlighted in the literature, which only highlights the difficulty of alliances with research centers, without considering an ecosystem and supply chain approach.

The most used incentives are related to taxation, such as the amortization of investments in 4.0 technologies and human capital training. Few studies showed how incentives can support the implementation of Industry 4.0, despite Jain and Ajmera (2020) stating that government facilities are one of the major enablers of Industry 4.0 adoption.

5.2. Discussion of quantitative results

Using a representative sample of Piedmont's local manufacturing units, the results firstly produce a positive and significant relationship between openness to Industry 4.0 and performance – *H1* ($\beta = 0.148^{***}$) – which shadows those found by Büchi et al. (2020a) and conceptually proposed by Vogel-Heuser and Hess (2016).

The positive relationship between openness to Industry 4.0 and incentives adoption is verified (*H4*). This result is in line with previous observations by Frank et al. (2016) and MISE (2018). However, the study should point out that the level of significance is rather weak, such that this evidence is open to question.

A positive relationship between openness to Industry 4.0 and four types of perceived barriers is found (*H2a, H2b, H2c,* and *H2d*). This result conforms with studies conducted by Birkel et al. (2019), Raj et al. (2020), and Stentoft et al. (2020). However, the paper should again note that the significance levels of some of these results are relatively weak, suggesting that this evidence remains open to interpretation.

It is possible to identify further results based on both the perception of barriers and incentives adoption. In this section, the paper considers some of the most noteworthy results.

In analyzing the results, the following elements are considered separately:

- the effects of perceived barriers on performance deriving from incentives (H3a, H3b, H3c, and H3d); and
- the effects of perceived barriers on performance deriving from the effect of perceived barriers on incentives.

The first set of relationships exhibits a positive and significant effect on performance from perceived barriers relating to knowledge (*H3a*, $\beta = 0.224^{*}$) and economic and financial issues (*H3b*, $\beta = 0.223^{*}$). However, there is no significant effect of the perception of cultural and systemic barriers on performance. The following provides an interpretation of these results.

It seems plausible that knowledgeable managers able to perceive barriers (according to the literature this idea is linked to the openness to Industry 4.0, but from our results this knowledge may be also independent from the openness to Industry 4.0) related to knowledge and economic and financial aspects are associated with firms that are able to produce better performance independently of incentives effects. This evidence is not statistically significant as far as perceived cultural and systemic barriers are concerned. In other words, firms that are able to perceive barriers that the firm itself is able to affect, are also able to perform better. In this circumstance, experts and interviewees highlight a greater relevance placed on knowledge-related barriers and economic and financial barriers.

The positive relationship between incentives adoption and performance is found to be statistically significant (*H5*, $\beta = 0.175^{*}$), according with the findings of the literature (Frank et al., 2016; MISE, 2018), which states that the more incentives firms adopt, the better their performance. This therefore reflects the aims that governments have in establishing industrial plans based around Industry 4.0 in order to promote productivity and competition (Dalenogare et al., 2018).

It is now possible to consider the effects of perceived barriers on performance as impacted by the extent of perceived barriers on incentives. Starting from the idea that the perception of barriers is a proxy of management's intelligence, our results indicate that the perception of barriers does not lead to the adoption of incentives. The only apparent exception to this is for economic and financial barriers, which produce a significant and negative relationship (*H6b*, β = -0.266*). This result suggests that the perception of economic and financial barriers limits the adoption of incentives because incentives are considered large enough to overcome barriers. Nevertheless, as noted previously, the effects of adopted incentives on performance are positive and statistically significant.

It can therefore be inferred that incentives are not specially designed to counter the types of barriers perceived by firms or, potentially, that firms cannot identify concrete benefits from incentives. In fact, the empirical results show that firms which adopt more incentives perform better, thereby shadowing the trend found in interviews, following which it was necessary to add B12 (*little information on public facilities to support investments in Industry 4.0*) to the other barriers previously identified.

6. Conclusions

The implementation of Industry 4.0 is a primary focus for economies across the world in order to improve the competitiveness and productivity of the manufacturing industry.

This paper, through a theoretical background analysis, identifies seven performances, 11 barriers, and the main existing government incentives through a mixed-method divided into two phases. The first phase, the qualitative analysis, consists of nine semi-structured in-depth interviews with experts and 11 multiple case studies. Despite the small size of the sample, the results reached theoretical saturation. The qualitative analysis integrates and validates the theoretical background, identifying a twelfth barrier. The qualitative analysis also highlights that the 12 barriers can be reclassified into four macro-categories linked to knowledge issues, economic-financial resources, cultural aspects, and system conditions.

The second phase, the quantitative analysis, explores the role of the performance, barriers and incentives identified in the previous phase. The questionnaire was developed to include the residual category of "other" in terms of performance, barriers, and incentives to assess whether entrepreneurs perceive further elements. The analysis of the quantitative results (absolute frequency = 0) allows verifying there are no additional elements to those already identified during the qualitative analysis.

The quantitative analysis confirms the hypotheses of the literature on a sample of 500 local manufacturing units and empirically verifies the relationships between openness to Industry 4.0 and performance influenced by perceived barriers to and incentives for Industry 4.0 adoption. The quantitative analysis adopts a parallel-serial multiple regression model. This technique identifies the direct and indirect effects of openness to Industry 4.0 using six equations – one for each of the five mediators and one for performance. The model is also assessed using the bootstrapping method on samples of 5000 units.

The results confirm that openness to Industry 4.0 provides opportunities to the manufacturing sector. However, this relation is affected by a set of intermediate influences, as explained below.

Openness selects firms that are able to perceive a wide variety of barriers. Following the direct effect of the perception of barriers on performance (via the intermediate effect of incentives), it is possible to find a positive and significant relationship between the perception of internal managerial variable and performance. This suggests that the perception of such barriers impacts performance independently of incentive adoption.

Furthermore, in general, barriers do not lead to the adoption of incentives, suggesting that incentives are perceived as relating to the barriers themselves. This is consistent with the finding that economic and financial barriers are seen as impediments to the adoption of incentives because incentives are not large enough to outweigh these barriers.

6.1. Theoretical contribution

The paper originally contributes to the managerial literature on Industry 4.0 in three ways: (a) by identifying the concepts of openness to Industry 4.0, performance, barriers, and incentives; (b) by operationalizing the concepts of openness to Industry 4.0, performance, barriers, and incentives; and (c) by verifying the literature on which the hypotheses of this study are based.

Additionally, the paper presents novel data in a research area that hitherto lacks empirical data on the barriers and incentives to Industry 4.0 adoption among firms.

The results verify that the higher the openness toward Industry 4.0, the higher the perceived performance. However, firms have difficulties in adopting Industry 4.0 because of different barriers, which are not all equally important for all firms. Finally, the results show that firms use incentives to overcome barriers, but not all barriers lead to incentive adoption.

6.2. Practical implications

The results presented in this paper also have implications on policy and management approaches.

First, the results suggest that entrepreneurs should adopt Industry 4.0 technologies in order to improve performance despite the perception of barriers, as the barriers identified in the theoretical background and confirmed by interviews and case studies may serve as guides for managers, as the review comprehensively covers the possible barriers relating to implementing Industry 4.0 technologies.

Secondly, since the results suggest that some managers prefer to overcome barriers without making use of incentives, it appears that some incentives are either not easy to use or not tailored to firms' needs. A remarkable example of this is the perception of economic and financial barriers, which even discourage firms from adopting incentives.

Third, the results suggest that governments should continue to create programs that promote the transition towards Industry 4.0 technologies in order to help firms overcome barriers such as *B7 (legal uncertainties)* and *B9 (lack of clear standards)*. More specifically, however, the results suggest that policymakers should promote incentives that recognize firms' needs and adopt more efficient bureaucratic processes in order to help firms overcome perceived barriers to adopting incentives.

6.3. Limitations and future research

One limitation of the research relates to the subjective nature of two of the considered variables: perceived performance and perceived barriers. More accurate results could be obtained by analyzing quantitative data in terms of the changes in costs and revenues.

Some results lead to unexpected outcomes that deserve further investigation, such as the negative relationships between perceived economic and financial barriers and incentives; the positive effect of knowledge and perceived economic and financial barriers on performance.

Furthermore, the study focuses on barriers and incentives. However, to help firms further improve their performance, future research could analyze different driving forces behind Industry 4.0 implementation and different types of incentives to determine if they respond differently to different barrier types.

Although this study considers a representative sample of 1732 firms, the still limited adoption of Industry 4.0 reduced the reference population to 500 firms. Studies on larger samples could evaluate how variables such as enterprise size, sector, propensity toward technological openness, and the different human resources can influence the relationship.

Finally, it may be of interest to further develop this research idea using samples from other countries to compare the results across countries and/or across different geographic areas.

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Supplementary materials

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