



## Industry 4.0 and production recovery in the covid era

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### ARTICLE INFO

#### Keywords:

COVID-19  
Industry 4.0  
SME  
Manufacturing  
Production recovery  
Mediator  
Digital reorganization  
Classical reorganization

### ABSTRACT

This study aims to use a quantitative analysis to explore the effects of openness to Industry 4.0 on the perceived production recovery post the COVID-19 pandemic, mediated by digital and classical reorganization. Openness to Industry 4.0 is measured by the breadth of the number of technologies adopted. The production recovery is measured by the perception of firms that a return to pre-COVID-19 production levels will happen within either 2021, 2022, or 2023. The study takes a representative sample of 2622 manufacturing small and medium enterprises across Italy (surveyed between October and November 2020) through a mediation analysis based on nonlinear probability models (KHB method). The results of the models show the following. First, openness to Industry 4.0 has a positive and significant direct effect on a perceived production recovery in the short term (within 2021) and medium term (within 2022 and 2023). Further, this effect is accelerated in the short term by digital reorganization and in the medium term by the addition of a classical reorganization. The research provides relevant managerial implications based on a large sample of current empirical data, showing that Industry 4.0 technologies, when adopted in tandem with the digital reorganization of production activity, can accelerate production recovery to pre-COVID-19 levels.

### 1. Introduction

The COVID-19 pandemic, labeled as a *black swan event*, has left an impact on institutions, organizations, businesses, people and, nearly every aspect of human life. Some experts point out that the effects of the pandemic are comparable—both in terms of global impact and socio-economic consequences—to the Great Depression of 1929, World War II, and the Great Recession of 2008–09 (Gupta, 2020; Roper and Turner, 2020).

Despite the measures introduced by governments worldwide to safeguard human lives (border closures, total or partial lockdowns, quarantines, blocks on productive, commercial, and entertainment activities), the virus continues to spread in uncontrollably (WHO – World Health Organization, 2021). Social distancing and stay-at-home advisories—except activities considered as essential (Ivanov and Dolgui, 2020)—remain top priorities on every country's policy agenda to slow the pandemic, save lives, and avoid overloading of their national health systems (Yoo and Managi, 2020).

One line of research underlines that the persistence of the pandemic has prompted many manufacturing firms to use technological innovation to implement robust and sustainable strategies (Narayanamurthy and Tortorella, 2021; Verma and Gustafsson, 2020) and attempt a return to a new normal (Lee and Trimi, 2021; Obradović et al., 2021). In many cases, the transformation has been achieved through the adoption of Industry 4.0 technologies (Lepore et al., 2021). Moreover, Spieske and Birkel (2021) show that during the pandemic crises, Industry 4.0 has helped increase efficiency in supply chain management, impacting readiness, response, recovery, and growth. Even if the literature concerning recovery remains scarce (Spieske and Birkel, 2021), some authors developing recovery models for the pandemic analyze it as an increase in production capacity (Paul and Chowdhury, 2021).

However, it is possible to identify another line of research that shows that Industry 4.0 is not always sufficient to face the COVID-19 crisis and that it should be accompanied by a digital reorganization (O'Leary, 2020; The Economist, 2020) and/or a classical reorganization of business operations (Rapaccini et al., 2020). Moreover, Industry 4.0 might

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<sup>1</sup> Disclosure Statement: the views expressed in the article are those of the author (Marco Pini) and do not necessarily reflect those of the institutions to which he belongs.

even generate some negative impacts due to the social distancing requirements enforced during the COVID-19 crisis. First, for example, Industry 4.0 may lead to a partial replacement of human labor by machine labor (Acioli et al., 2021). Second, smart/remote working and the use of related online platforms might increase cybersecurity issues such as phishing and data breaches (Melluso et al., 2020).

From an empirical perspective, there is still a lack of understanding of exactly how many technologies are needed to accelerate the return to pre-COVID-19 productivity levels in the short and medium terms while also considering the different characteristics of firms and if there are variables that can modify the intensity of this phenomenon. Moreover, there is a lack of empirical verification of the role played by Industry 4.0 in the recovery of manufacturing activity to pre-COVID-19 levels for SMEs. Such analyses may support managers and policymakers to identify the most appropriate solutions for better resilience of SMEs, which have been the most affected by the pandemic (Juergensen et al., 2020) given their limited resources (human, financial and technical), in particular financial (Cowling et al., 2020), compared to larger firms (Martin et al., 2019). Owing to the limited number of studies examining the impact of Industry 4.0 on production recovery to pre-COVID-19 levels, it is relevant to answer the following research questions (RQs).

RQ1 - What is the degree of openness to Industry 4.0 that will facilitate the return of productivity to pre-COVID-19 levels?

RQ2 - Are there any variables that may influence this relationship?

Thus, RQ1 addresses the first research stream, and RQ2 considers the role of business reorganization highlighted by the second research stream. The need to answer these RQs is more relevant considering the persistence of the pandemic and can only be assessed through the perception of business managers (a subjective measure).

Therefore, this study uses a quantitative analysis to explore the effect of openness to Industry 4.0 on the perceived production recovery in the short and medium run (within 2021, 2022, and 2023), mediated by intermediary effects.

It identifies openness to Industry 4.0, perceived production recovery, and intermediary effects, following the theoretical background. The study operationalizes the concept of openness to Industry 4.0 as the breadth of 4.0 technologies adopted (Büchi et al., 2020; Cugno et al., 2021). Perceived production recovery is operationalized as the perception to return to pre-COVID-19 production levels (Paul and Chowdhury, 2021) either within 2021, 2022, or 2023. The intermediary effects considered are a digital reorganization and a classical reorganization (Rapaccini et al., 2020).

The study analyzes a representative sample of 2622 manufacturing SMEs in Italy. This sample is chosen because of the relevance of the Italian manufacturing sector (Eurostat, 2021), which has recorded a large share (13.3%) of the value added in the EU-27's manufacturing sector and more than 55% of the value added in Europe's non-financial sector (European Investment Bank, 2020). The sector has a turnover of around 900 billion euros, preceded only by Germany and represents about two-thirds of the total employment. Moreover, SMEs represent the backbone of national economies (Morais and Ferreira, 2020). The focus on SMEs is corroborated by the fact that larger firms have access to more resources (primarily financial and human) that enable faster recovery than SMEs (Horváth and Szabó, 2019).

The literature highlights the need and urgency to understand the ability and speed of SMEs to recover to post-COVID-19 crisis. Brem et al. (2021) emphasize the importance of providing perspective on the implications of a phenomenon that will have a disruptive and comprehensive impact over the long run. Sneider and Singhal (2020) point out that past times will not return exactly as they were, and thus, preparation for a new post-pandemic normal is necessary.

The originality of this study lies in enriching the literature on the topic of Industry 4.0 and production recovery in the COVID-19 era. To this end, it provides a detailed understanding of the recovery of manufacturing SMEs. It uses a large sample of current empirical data to verify the time horizon of this recovery, the contribution of the adoption

of Industry 4.0 technologies, digital reorganization, and classical reorganization of business activities.

The study contributes to the literature in two ways. First, the methodology operationalizes the concepts of openness to Industry 4.0, perceived production recovery, digital reorganization, and classical reorganization. Second, the study uses a large sample of current empirical data to test the relationship between openness to Industry 4.0 and the perceived production recovery mediated by the intermediary effects.

In addition to theoretical contributions, this study provides practical advice to entrepreneurs and managers about the role of Industry 4.0. It highlights both the technological adoption and reorganization of activities as factors that can help firms with developing post-COVID-19 resilience.

The remainder of this study is structured as follows. Section 2 defines the theoretical background and the research hypotheses, and Section 3 describes the methodology. Further, Section 4 reports the main results, and Section 5 discusses these results. Finally, Section 6 highlights the most promising theoretical and practical implications, identifies limitations, and proposes avenues for future research.

## 2. Theoretical background and hypotheses development

### 2.1. Theoretical background

The discovery of the severe acute respiratory syndrome SARS-CoV-2, better known by its acronym COVID-19, and the subsequent spread of the virus have generated two primary consequences. The first consequence is the need to develop new therapies, vaccines, and infection control practices (Chesbrough, 2020). The second has been the awareness that the future world will not be the same as before, requiring the need to implement innovative behaviors and new requirements (Ebersberger and Kuckertz, 2021). Innovation is likely to respond to these changes, and enterprises will play a central role in these transformations (Breier et al., 2021; Kraus et al., 2020).

Each country has, at different times and with varying intensities, experienced an initial phase of total lockdown except for essential activities (food, healthcare, etc.)—also defined as the great lockdown (Greene and Rosiello, 2020). From the perspective of firms, this phase is based on a reconfiguration of the production activities of some firms to fill the shortage of health and personal protective equipment. Examples include automakers (i.e., Tesla, Ford, GM, and Ferrari; Bergami et al., 2021) and aerospace companies that transformed their operations in favor of manufacturing health ventilator components (Morse, 2020) and face-shields (McConnell, 2020). Other examples of manufacturing conversion include the production of sanitizing gels by firms in the wine and spirits industry (e.g., Pernod Ricard; Abboud et al., 2020) and plastic bottles for sanitizers by large perfume manufacturers (e.g., LVMH Moët Hennessy Louis Vuitton SE). The lockdown has not affected the rapid production of medical and healthcare equipment made through 3D printing technologies, flexible manufacturing systems, big data analytics, and smart healthcare wearables (Brem et al., 2021). Technological adoption and/or reconfigurations of production activity has allowed companies—including those belonging to sectors not considered essential—to remain open by transforming their production activities into essential activities.

The second phase of the COVID-19 emergency now requires designs for the restart of activities to contain the spread of infection through prevention, protection, and sanitation practices for workplaces and workers. From the perspective of firms, Industry 4.0 technologies can play a central role (Brem et al., 2021; Chesbrough, 2020) in the following processes. (i) Workplace sanitization; (ii) devices for tracking; (iii) rapid, inexpensive, and widely applicable diagnostic methods to assess symptoms (such as temperatures with visors during the workday, self-assessment apps, teleradiology); (iv) planned access management with apps to limit crowding at entrances during the workday; (v) space

and flow simulation systems; (vi) and use of virtual reality for job training and remote employee and customer counseling.

After the second phase of partial reopening, the pandemic intensified in different countries, resulting in the need for new partial or total lockdowns, quarantines, and a freeze of non-essential commercial, educational, and entertainment activities. The persistence of the health emergency highlights the need for firms to equip themselves with tools that allow them to rethink and redesign their activities in the following scenarios (Centro Studi Confindustria, 2020):

- realization of production volumes in periods of strong sales discontinuity due to imbalances in demand
- need to activate interactions with supply and distribution channels in times of limited mobility of goods
- need to manage relationships with employees, customers, and suppliers in periods of interpersonal distancing
- impossibility to conduct sector fairs and events for the promotion of products in person and the need to identify new forms of conviviality and spaces for the promotion of the company

The pandemic event has created unforeseen disruptions of significant size. These disruptions have had substantial negative consequences on the returns on sales, returns on profit, stock returns, brand image, employment, buyer safety, and overall supply performance (Paul and Chowdhury, 2021). These disruptions have had an immediate impact on supply chains affecting the supply of one or more components of the network and the linkage of production, distribution, and transportation (Ivanov, 2020).

The theoretical study by Wenzel et al. (2020) identifies four possible strategies for businesses to pursue after a pandemic: (1) *exit*—discontinuing the firm's business activities; (2) *retrenchment*—cost-cutting measures that potentially reduce the scope of a firm's business activities; (3) *persevering*—preservation of the status quo of a firm's business activities in times of crisis; (4) *innovating*—conducting strategic renewal as a response to the crisis.

Focusing on the last and challenging solution of *innovating*, both the academic and gray literature agree that the adoption of a particular type of innovation—Industry 4.0—can support the management of firms in the COVID-19 era (Acioli et al., 2021; Brem et al., 2021; Chesbrough, 2020; Ebersberger and Kuckertz, 2021; The Economist, 2020).

Industry 4.0 refers to the fourth industrialization process of the manufacturing sector or what some authors call the Fourth Industrial Revolution or (re)evolution of re(e)volutions. This definition considers the combinatorial and exponential impact of cyber-physical systems and Industry 4.0 technologies, enabling a smart grid within the enterprise. The related environment interconnects employees, customers, suppliers, products, machinery, and manufacturing facilities (Schneider, 2018). The changes are fueled by emerging technologies that offer a better way to organize and manage key business processes, such as prototyping, development, supply, manufacturing, and logistics. The Industry 4.0 environment ensures its operability (Lu, 2017) through the following steps: (i) enabling interactions between value and supply chain actors through the horizontal, vertical, and end-to-end integration of the enterprise; (ii) interoperability—enabling productions within and across enterprise boundaries based on demand. This environment is realized through cyber-physical systems—systems capable of creating a digital representation of the physical world in which the enterprise operates. Compared to the previous industrial revolutions, Industry 4.0 stimulates development, production, distribution, and performance in a physical-digital-physical loop. Industry 4.0 arises from a convergence of operations technologies (derived from manufacturing) and information technologies (developed in the users' world). These technologies can be classified into nine main pillars (Rüßmann et al., 2015): advanced manufacturing, additive manufacturing, internet of things, cloud computing, big data, augmented reality, simulation, horizontal and vertical integration, and cyber security. Finally, Industry 4.0

technologies require the enterprise to be organized to apply them properly (Porter and Heppelmann, 2015). Indeed, experimentation of these technologies in the first two phases of the COVID-19 pandemic generated numerous initiatives that enabled improved business survival (Ivanov and Dolgui, 2020). Such support of Industry 4.0 for survival and recovery in the COVID-19 era is linked to its ability to improve productivity (Fragapane et al., 2020; Kagermann et al., 2013) and accelerate production (Lepore et al., 2021).

However, the current literature on Industry 4.0 and COVID-19 recovery seems to be divided into two main research streams. The first research stream supports the idea that Industry 4.0 can have a positive impact on the post-COVID-19 recovery of businesses (Spieske and Birkel, 2021). Conversely, the authors of the second research stream emphasize the need to accompany the adoption of Industry 4.0 technologies with a classical or digital reorganization of the business activity (Rapaccini et al., 2020) while also focusing on the risks that Industry 4.0 can bring during and after the pandemic. They draw particular attention to social risks related to job losses (Acioli et al., 2021) and cyber security issues (Melluso et al., 2020).

When developing recovery models for the pandemic, the literature has focused on two recovery strategies: (i) increase in production capacity and (ii) increase in raw material supply (El Baz and Ruel, 2021; Ivanov and Dolgui, 2020; Nagurney, 2021; Paul and Chowdhury, 2021). This study focuses on analyzing recovery production to assess how SMEs can achieve pre-COVID-19 (2019) production levels (Fig. 1).

## 2.2. Hypotheses development

To empirically verify what emerges from the two research streams reported in the theoretical background and answer the related RQs, the following research hypotheses are formulated.

Following the literature, Industry 4.0 is traditionally represented by the measure of firms' openness to Industry 4.0 (Büchi et al., 2020), considering the breadth of its technologies adopted (Büchi et al., 2021; Cugno et al., 2021). Recovery is measured as the increase in production capacity (Paul and Chowdhury, 2021).

Therefore, answering RQ1, which fits into the first research stream, the following research hypotheses are posed.

H1<sub>21</sub> – Openness to Industry 4.0 leads to perceived production recovery to pre-COVID-19 levels within 2021.

H1<sub>22</sub> – Openness to Industry 4.0 leads to perceived production recovery to pre-COVID-19 levels within 2022.

H1<sub>23</sub> – Openness to Industry 4.0 leads to perceived production recovery to pre-COVID-19 levels within 2023.

Moreover, the second research stream states that in the COVID-19 era, the environment for Industry 4.0 requires further transformations through the implementation of digital and classical reorganizations (Rapaccini et al., 2020).

Digital reorganization is defined as follows: (i) increased use of digital work technologies (Nambisan, 2017; Narayanamurthy and Tortorella, 2021; Richter, 2020); (ii) increased use of online sales channels (Brem et al., 2021); (iii) staff training activities on new digital technologies (Liguori and Winkler, 2020); (iv) management training on new digital business models (Elia et al., 2020).

Classical reorganization is defined as follows: (i) improving managerial skills (Ivanov and Dolgui, 2021); (ii) reorganizing sales methods to encourage social distancing (e.g., take-away and home delivery) (Roggeveen and Sethuraman, 2020); (iii) reorganization of working hours in times of interpersonal distancing (Galasso and Foucault, 2020); (iv) changes in space, work environment, and tasks (Carnevale and Hatak, 2020); (v) reorganization of the range of after-sales service offerings that allow for the maintenance or better use of products (Heinonen and Strandvik, 2020). Therefore, answering RQ2, which fits into the second research stream, the following research hypotheses are posed.

H2 – Openness to Industry 4.0 leads to the digital reorganization of

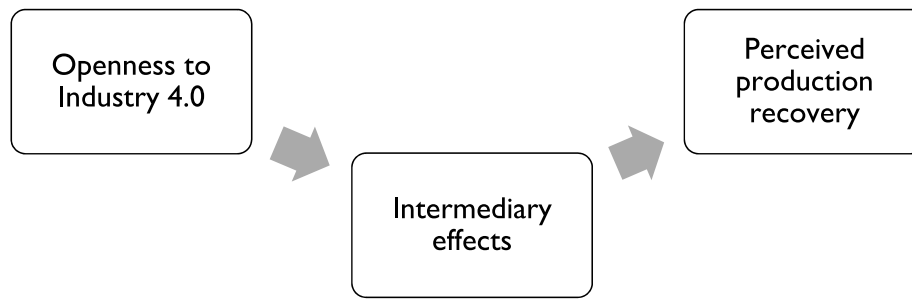


Fig. 1. Conceptual framework.

firms.

H3 – Openness to Industry 4.0 leads to the classical reorganization of firms.

The literature points out that digital and classical reorganizations impose transformations such as the following: (O’Leary, 2020; Rapacini et al., 2020; The Economist, 2020): (i) increasing the number of shifts; (ii) purchasing additional machinery; (iii) utilizing downtime; (iv) hiring human resources to increase the production capacity. These changes support and accelerate the recovery of production to pre-COVID-19 levels (Paul and Chowdhury, 2021). Therefore, the following research hypotheses are posed:

H4<sub>21</sub> – Digital reorganization accelerates perceived production recovery within 2021.

H4<sub>22</sub> – Digital reorganization accelerates perceived production recovery within 2022.

H4<sub>23</sub> – Digital reorganization accelerates perceived production recovery within 2023.

H5<sub>21</sub> – Classical reorganization accelerates perceived production recovery within 2021.

H5<sub>22</sub> – Classical reorganization accelerates perceived production recovery within 2022.

H5<sub>23</sub> – Classical reorganization accelerates perceived production recovery within 2023.

Fig. 2 summarizes the research hypotheses describing a model investigating the relationship between the openness to Industry 4.0 and perceived production recovery within 2021, 2022, and 2023, with two mediators: digital reorganization and classical reorganization.

### 3. Methodology

#### 3.1. Data

The data for the analyses come from a survey conducted by Unioncamere (Italian Union of Chambers of Commerce) at the end of 2020 on a representative sample of 3000 Italian manufacturing firms with the number of employees ranging between 5 and 499 (Unioncamere, 2020). The stratification considers three dimensions for each firm: (i) industry—24 divisions of section C manufacturing sector of the Nace Rev.2 classification (Eurostat, 2021); (ii) size class in terms of employees—micro (5–9 employees), small (10–49 employees), medium (50–249 employees), and large (250–499 employees); (iii) geographical location, distinguishing for areas connoted by the different quality of infrastructure and economic development levels (North-West, North-East, Center, South).

The survey considers the following areas of research focus. The first area of focus concerns the 11 Industry 4.0 technologies adopted (advanced manufacturing, additive manufacturing, augmented reality, big data, cloud computing, cyber security, internet of things, simulation, horizontal and vertical integration, artificial intelligence, and block-chains). The second area of focus relates to the different modalities of digital reorganization (increased use of digital working technologies; increased use of online sales channels; staff training activities on new digital technologies; management training on new digital business models) and classical reorganization (improvement of managerial skills; reorganization of sales methods to encourage social distancing; reorganization of working time to reduce costs; initiation of new

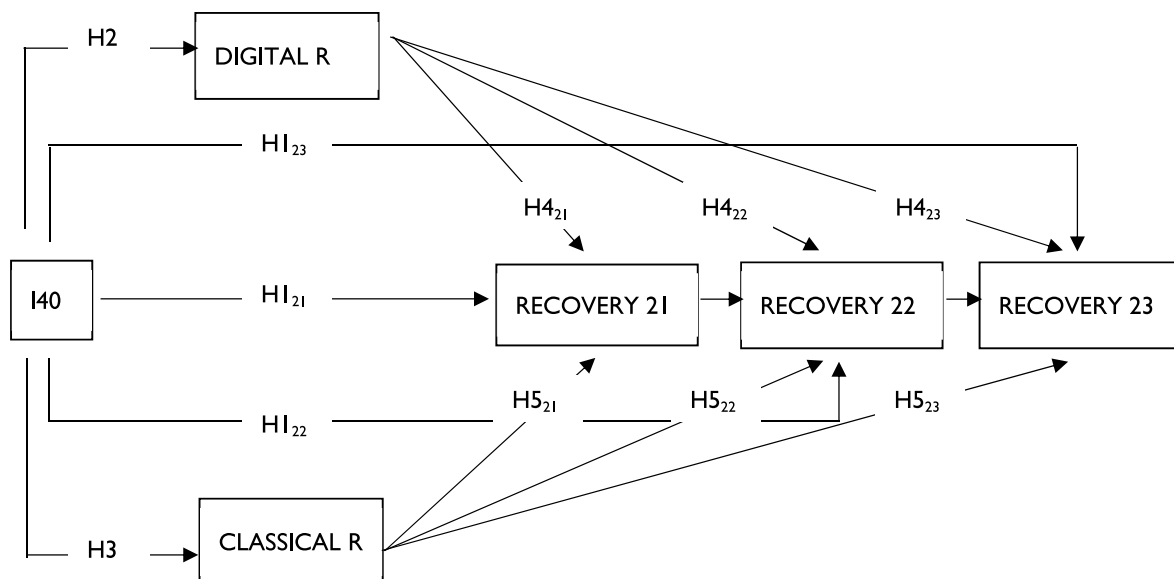


Fig. 2. Research hypotheses model.



transformation processes for staff; conversion of the range of services offered). The third area of focus is on the recovery of production to pre-COVID-19 levels within the three years following the pandemic (2021, 2022, and 2023). The fourth area of focus concerns the firms' characteristics (the share of employees who are graduates; the number of years since the inception of business activities; the firms' size considering the number of employees; the technology intensity of the industries; the location of the firms).

The maximum sampling error is small ( $e = 1.8\%$ ;  $\alpha = 0.95\%$ ). The survey was conducted by a professional contractor using the CATI (Computer-Assisted Telephone Interviewing) method to gather qualitative and quantitative information about the firm. Several preliminary briefings were held with the contractor aimed at explaining the exact meaning of the questions to the interviewers, with particular reference to those concerning Industry 4.0. The quality of the data was subsequently validated. Furthermore, according to Dorling and Simpson (1999), the quality of the data was ensured by the fact that they came from a public agency confirming a high response rate and thus being representative of the population.

With the focus being on SMEs with up to 249 employees, the database comprises 2925 manufacturing SMEs (5–249 employees), corresponding to 2.2% of all Italian firms and 3.6% in terms of employees. Of the sampled 2925 SMEs, 303 SMEs never ceased operations because they belonged to essential industries or because they transformed their business activities into essential activities. Therefore, this study focuses on the remaining 2622 SMEs that stopped their activities and that consequently had a fall in production in 2020 when compared to the pre-COVID-19 levels. The survey contains two specific sections: one on Industry 4.0 (adoption/non-adoption; technologies adopted); one on the COVID-19 crisis, focusing on the impact, the recovery time (within 2021, within 2022, within 2023, never, without response), and the business strategies to overcome the crisis. Information about the firm's characteristics (skills, age, size, technological intensity of economic sector, and geographical area) comes from the survey and the administrative archives.

### 3.2. Method

A mediation analysis (Hayes, 2018) was conducted to measure the effect of the openness to Industry 4.0 (independent variable: I40) on the possibility that the return to pre-COVID-19 production levels would happen within 2021, 2022, or 2023 (dependent variable: RECOVERY 21; RECOVERY 22; RECOVERY 23, respectively). The direct effects were decomposed from the indirect effects via two mediators: digital reorganization (DIGITAL R) and classical reorganization (CLASSICAL R).

As the outcome is binary, the analysis applies the KHB method (command *khb* in STATA), thus providing an unbiased decomposition of total effects into direct and indirect effects for nonlinear probability models (Breen et al., 2013; Kohler et al., 2011).

The path explained in Fig. 2 is estimated through the following three equations:

$$M_{1i} = i_{M_1} + a_1X_i + d_1C_i + \varepsilon_{M_1} \quad (1)$$

$$M_{2i} = i_{M_2} + a_2X_i + d_2C_i + \varepsilon_{M_2} \quad (2)$$

$$\text{Prob}(Y_i = 1|X_i, M_{1i}, M_{2i}, C_i) = \Phi(i_Y + c'X_i + b_1M_{1i} + b_2M_{2i} + d_3C_i + \varepsilon_Y) \quad (3)$$

where  $M_1$  and  $M_2$  are the mediators (respectively, DIGITAL R and CLASSICAL R),  $Y$  is the dependent variable (for each type of analysis, RECOVERY 21, RECOVERY 22, and RECOVERY 23, respectively),  $X$  is the independent variable (I40), and  $C$  is the vector including all control variables.  $\Phi$  is a standard normal cumulative distribution function;  $\varepsilon$  is the random error term;  $i_{M_1}$ ,  $i_{M_2}$ , and  $i_Y$  are the regression constants.

Equations (1) and (2) are estimated using linear regression (OLS), while Equation (3) is estimated using the probit regression method. In

Equations (1) and (2), the coefficients  $a_1$  and  $a_2$  are the respective effects of the independent variable  $X$  on each mediator ( $M_1$ ,  $M_2$ ).

In Equation (3), the coefficient  $c'$  is the direct unmediated effect of the independent variable  $X$  on the dependent variable  $Y$  when adjusted for the mediators. Coefficients  $b_1$  and  $b_2$  are the respective effects of the mediators  $M_1$  and  $M_2$  on  $Y$  when adjusted for  $X$ .

The indirect effect measures the effect of  $X$  on  $Y$  that is explained by the mediators. Specifically, in the presence of the two mediators ( $M_1$ ,  $M_2$ ), there are two indirect effects—one related to digital reorganization ( $a_1b_1$ ) and the other related to classical reorganization ( $a_2b_2$ ). The sum of these two effects constitutes the total indirect effect.

Thus, the total effect ( $c$ ) of  $X$  on  $Y$  corresponds to the sum of the direct effect ( $c'$ ) and the total indirect effect ( $a_1b_1 + a_2b_2$ ). Thus, analytically,  $c = c' + (a_1b_1 + a_2b_2)$ . Stata version 15 is used for all the estimates.

### 3.3. Variables description

#### 3.3.1. Dependent variable

The dependent variable concerns the firm's perceived production recovery within 2021, 2022, and 2023. In light of the strong economic crisis due to the pandemic, this study investigates the estimated times for production to recover to pre-COVID-19 levels. While the literature contains some studies that have examined the post-COVID-19 economic recovery at the macro level (De Backer et al., 2021; Sharma et al., 2021), there is a gap with respect to firm level studies.

The analyses are based on three binary dependent variables: (i) the first taking value 1 if the firm expects to rise back to pre-COVID-19 production levels within 2021; (ii) the second taking value 1 if the firm expects to rise back to pre-COVID-19 production levels within 2022; (iii) the third taking value 1 if the firm expects to rise back to pre-COVID-19 production levels within 2023.

#### 3.3.2. Main independent variable

The main independent variable concerns the openness to Industry 4.0 considering eleven related technologies: (i) advanced manufacturing; (ii) augmented reality; (iii) internet of things; (iv) big data; (v) cloud computing; (vi) cyber security; (vii) additive manufacturing; (viii) simulation; (ix) horizontal and vertical integration; (x) blockchain; (xi) artificial intelligence. These typologies correspond to those defined by Rüßmann et al. (2015), adopted by the Minister of Economic Development of Italy (2017), and considered in recent studies (Büchi et al., 2020; Cugno et al., 2021). Moreover, this study considers block chain (Kayikci et al., 2020; Kimani et al., 2020) and artificial intelligence (Loureiro et al., 2021). Specifically, openness to Industry 4.0 is measured through a combination of these eleven technologies—calculating 11 dummies (equals 1 for each technology if the firm implemented it). The variable, openness to Industry 4.0 (I40), is an indicator corresponding to the sum of these 11 dummies, thus ranging from 0 (no technology adopted) to 11 (all technologies adopted). This method is adopted in recent studies (Cugno et al., 2021).

#### 3.3.3. Mediators

Digital reorganization is defined as follows: (i) increased use of digital working technologies; (ii) increased use of online sales channels; (iii) staff training activities on new digital technologies; (iv) management training on new digital business models. It is thus measured as a combination of these four kinds of reorganization—calculating four dummies (equals 1 for each kind of reorganization if the firm implemented it). DIGITAL R is an indicator corresponding to the sum of these four dummies, ranging from 0 (no reorganization adopted) to 4 (all kinds of reorganization adopted).

Classical reorganization is defined as follows: (i) improvement of managerial skills; (ii) reorganization of sales methods to encourage social distancing; (iii) reorganization of working time to reduce costs; (iv) initiation of new transformation processes for staff; (v) conversion of the range of services offered. It is thus measured as a combination of these

five kinds of reorganization by calculating five dummies (equals 1 for each kind of reorganization if the firm implemented it). CLASSICAL R is an indicator corresponding to the sum of these five dummies, ranging from 0 (no reorganization adopted) to 5 (all kinds of reorganization adopted).

### 3.3.4. Control variables

According to the literature, human capital is a factor that positively affects economic growth (Becker, 1993; Schultz, 1993), supporting a firm's performance and competitive advantage (Agarwala, 2003; Marimuthu et al., 2009). Thus, the analysis is controlled for this factor by including a continuous variable (SKILLED WF) indicating the share of graduate employees.

Age is a factor potentially influencing the firm's performance (Coad et al., 2018; Rossi, 2016). Therefore, the analysis controls for the firm's age by including a continuous variable (AGE) indicating the number of years since the firm's inception, in line with Bettiol et al. (2019).

The analysis also controls for size in view of Gibrat's law (Calvo, 2006)—considering the possible influence of the firm's size on its performance (Lee, 2009; Nireesh and Thirunavukkarasu, 2014)—by including a continuous variable (SIZE) related to the number of employees, in line with Bettiol et al. (2019).

Concerning the sectors, the analysis is in line with other studies (Dalenogare et al., 2018) to control for the technology intensity of the industries. The analysis includes a variable (HIGH-TECH) taking value 1 if the firm belongs to a high or medium-high technologically intensive industry (following the EUROSTAT classification of manufacturing industries by technological intensity).

As highlighted in the literature, location is a factor that potentially affects the firm's competitiveness (Ascani et al., 2020; Audretsch and Dohse, 2007). This is particularly relevant in Italy, where geography-linked socio-economic differences are relevant (Del Monte and Papagni, 2003; Giovannetti et al., 2013). Thus, the analysis controls for this factor using three geographic dummies: NORTH-WEST, NORTH-EAST, and CENTER (SOUTH as reference category).

For the description of all variables, see Table 1.

**Table 1**  
Description of variables.

Variables	Description
<i>Dependent variable</i>	
RECOVERY 21	Dummy: 1 if the firm expects to rise back to pre-COVID-19 levels within 2021
RECOVERY 22	Dummy: 1 if the firm expects to rise back to pre-COVID-19 levels within 2022
RECOVERY 23	Dummy: 1 if the firm expects to rise back to pre-COVID-19 levels within 2023
<i>Independent variables</i>	
I40	Discrete: number of Industry 4.0 technologies adopted by the firm (0–11)
<i>Mediators</i>	
DIGITAL R	Discrete: number of digital reorganizations adopted by the firm to overcome the COVID-19 crisis (0–4)
CLASSICAL R	Discrete: number of non-digital (classical) reorganizations adopted by the firm to overcome the COVID-19 crisis (0–5)
<i>Control variables</i>	
SKILLED WF	The share of graduated employees (0–100)
AGE	Number of years since inception
SIZE	Number of employees
HIGH-TECH	Dummy: 1 if the firm belongs to a high or medium-high technology-intensive industry (following the EUROSTAT classification of manufacturing industries by technological intensity)
NORTH-WEST	Dummy: 1 if the firm is located in the North-West of Italy
NORTH-EAST	Dummy: 1 if the firm is located in the North-East of Italy
CENTER	Dummy: 1 if the firm is located in the Center of Italy
SOUTH	Dummy: 1 if the firm is located in the South of Italy

## 4. Results

### 4.1. Descriptive analysis

Table 2 reports the relationships between Industry 4.0 adoption and the estimates for recovery of production. The results show that the percentage of SMEs perceiving a return to pre-COVID-19 production levels within 2021 is higher among those who have adopted Industry 4.0 technologies (45% against 37% of SMEs who have not adopted Industry 4.0 technologies). Conversely, 29% of the SMEs did not answer or estimated that the firm will never recover to pre-COVID-19 levels. This percentage decreases when estimated for 2022 and 2023 as most firms adopting Industry 4.0 technologies perceive a recovery to pre-COVID-19 production levels within 2021.

Table 3 shows that the sample analyzed comprises 2622 manufacturing SMEs. The share of firms expecting to return to pre-COVID-19 production levels within 2021 is 38.3%. This share becomes 62.0% when the expectation of return is within 2022 and 70.8% for within 2023. The openness to Industry 4.0 is found to be minimal as the average number of technologies adopted by each firm (among the 351 adopting firms) is 1.4 on a scale of 1–11. The share of graduate employees is also considerably low (6.2%), while the average age of firms is 36 years. The average size of the firms surveyed is 29 employees. Almost 20% of the firms belongs to high or medium-high technologically intensive sectors. From a geographical perspective, numerous firms are located in Northern Italy—31.9% in the North-West and 28.9% in the North-East. These shares are smaller in the Center (21.0%) and the South (18.2%).

Table 4 displays the correlation matrix. The collinearity problem does not emerge here as the correlation coefficients are all below the critical value of 0.7 (Tabachnick and Fidell, 1996), and the Variance Inflation Factor (VIF) values are below the critical value of 10 (Yoo et al., 2014).

### 4.2. Confirmatory analysis

Tables 5 and 6 report the results of the multiple parallel model, considering the relationship between openness to Industry 4.0 (I40) and the perceived recovery of production within 2021, 2022, and 2023 (RECOVERY 21, RECOVERY 22, RECOVERY 23, respectively), driven by the direct and indirect effects of the two intermediary variables.

Fig. 3 summarizes the results of the confirmatory analysis showing the hypotheses that are supported or not supported and the consequently accepted or rejected ones. Of the 11 hypotheses, H3 and H5<sub>21</sub> are not supported, while the others are supported and accepted.

H<sub>121</sub>, H<sub>122</sub>, and H<sub>123</sub> propose that greater openness to Industry 4.0 will lead to the recovery of production to pre-COVID-19 levels within 2021, 2022, and 2023, respectively. The analysis shows a positive and significant relationship between these two factors in each case ( $c^1 = 0.076$ ,  $p < 0.1$ ;  $c^1 = 0.096$ ,  $p < 0.1$ ; and  $c^1 = 0.090$ ,  $p < 0.1$ , respectively). Consequently, H<sub>121</sub>, H<sub>122</sub>, and H<sub>123</sub> are accepted.

H2 states that greater openness to Industry 4.0 leads to a digital reorganization in firms. The hypotheses test shows a positive and significant relationship between these two factors ( $a_1 = 0.063$ ,  $p < 0.01$ ). Hence, H2 is accepted.

H3 states that greater openness to Industry 4.0 leads to a classical reorganization in firms. In this case, the empirical results do not indicate a significant relationship ( $a_2 = 0.000$ ,  $p > 0.1$ ). Consequently, H3 is not supported.

H<sub>421</sub>, H<sub>422</sub>, and H<sub>423</sub> state that the digital reorganization of firms accelerates the perceived production recovery within 2021, 2022, and 2023, respectively. The empirical results indicate a positive and significant relationship between these two factors in each case ( $b_1 = 0.164$ ,  $p < 0.01$ ;  $b_1 = 0.238$ ,  $p < 0.01$ ; and  $b_1 = 0.237$ ,  $p < 0.01$  respectively). Thus, H<sub>421</sub>, H<sub>422</sub>, and H<sub>423</sub> are accepted.

H<sub>521</sub>, H<sub>522</sub>, and H<sub>523</sub> propose that the classical reorganization of

**Table 2**  
Industry 4.0 and recovery.

Adoption of 4.0 technologies	RECOVERY 21	RECOVERY 22	RECOVERY 23	Never	Without answer	Recovery within the three years (2021, 2022, or 2023)
n.	1003	623	230	173	593	1856
yes	45%	25%	7%	4%	18%	77% <sup>a</sup>
no	37%	24%	9%	7%	23%	70% <sup>b</sup>
Dif.	8%	1%	-2%	-3%	5%	

<sup>a</sup> Here, 77% corresponds to the sum of SMEs adopting Industry 4.0 technologies, which estimated recovering production levels within 2021, 2022, or 2023, out of the total of 2622 SMEs.

<sup>b</sup> Further, 70% corresponds to the sum of SMEs not adopting Industry 4.0 technologies, which estimated recovering production levels within 2021, 2022, or 2023, out of the total of 2622 SMEs.

**Table 3**  
Summary statistics.

	Obs	%			
RECOVERY 21	2622	0.383			
RECOVERY 22	2622	0.620			
RECOVERY 23	2622	0.708			
HIGH-TECH	2622	0.181			
NORTH-WEST	2622	0.319			
NORTH-EAST	2622	0.289			
CENTER	2622	0.210			
SOUTH	2622	0.182			
	Obs	Mean	Std. Dev.	Min	Max
I40 <sup>a</sup>	351	1.447	0.656	1	3
DIGITAL R	2622	0.125	0.401	0	3
CLASSICAL R	2622	0.352	0.621	0	4
SKILLED WF	2622	6.224	12.587	0	100
AGE	2622	37.495	12.191	4	117
SIZE	2622	29.261	40.418	4	242

<sup>a</sup> Based on all SMEs adopting Industry 4.0 technologies.

firms accelerates the perceived production recovery within 2021, 2022, and 2023, respectively. In this case, the hypotheses test does not indicate the presence of a significant relationship for H5<sub>21</sub> ( $b_2$  -0.037,  $p > 0.1$ ), while a positive and significant relationship is determined in the case of H5<sub>22</sub> and H5<sub>23</sub> ( $b_2 = 0.076$ ,  $p < 0.1$ ; and  $b_2 = 0.252$   $p < 0.01$  respectively). Hence, H5<sub>21</sub> is not supported, but H5<sub>22</sub> and H5<sub>23</sub> are accepted.

## 5. Discussion

Management literature states that Industry 4.0 can have a significant and positive impact on manufacturers and manufacturing firms (Pozzi et al., 2021) during and after the COVID-19 pandemic. This is due to the added ability to improve firm productivity (Fragapane et al., 2020; Kagermann et al., 2013) and accelerate production in the COVID-19 era (Lepore et al., 2021). This study empirically verifies these effects on the perceived recovery of production to pre-COVID-19 levels.

The first research question is logically positioned in the first research stream identified in the literature. Using a representative sample of 2622

Italian manufacturing SMEs, the results show a positive and significant relationship between the openness to Industry 4.0 and the perceived estimates of production recovery within 2021, 2022, and 2023 (H1<sub>21</sub>, H1<sub>22</sub>, and H1<sub>23</sub> respectively). The role of Industry 4.0 as a support to production recovery is also clear when analyzing the differences between firms adopting the new technologies and those not doing so (Table 4). In fact, the percentage of firms that perceive a recovery to pre-COVID-19 production levels within 2021 is higher for firms adopting Industry 4.0 technologies (45%) against the ones who have not adopted them (37%). These results confirm the literature on Industry 4.0 as a facilitator to return to a new normal (Lee and Trimi, 2021) and supporting post-COVID-19 survival and recovery (Spieske and Birkel, 2021) through improved firm productivity (Fragapane et al., 2020; Kagermann et al., 2013) and accelerated production in the COVID-19 era (Lepore et al., 2021). Moreover, the results show a feature not analyzed thus far in the literature—this relationship changes over time, with the rate of change increasing in the first two years and stabilizing in the third year while remaining positive and significant.

**Table 5**  
Direct effects.

	Effect	Robust SE	z	p	LLCI	ULCI
I40 à RECOVERY 21	0,076	0047	1,62	<0.100	-0,016	0169
I40 à RECOVERY 22	0,096	0050	1,91	<0.100	-0,002	0193
I40 à RECOVERY 23	0,090	0053	1,71	<0.100	-0,013	0194

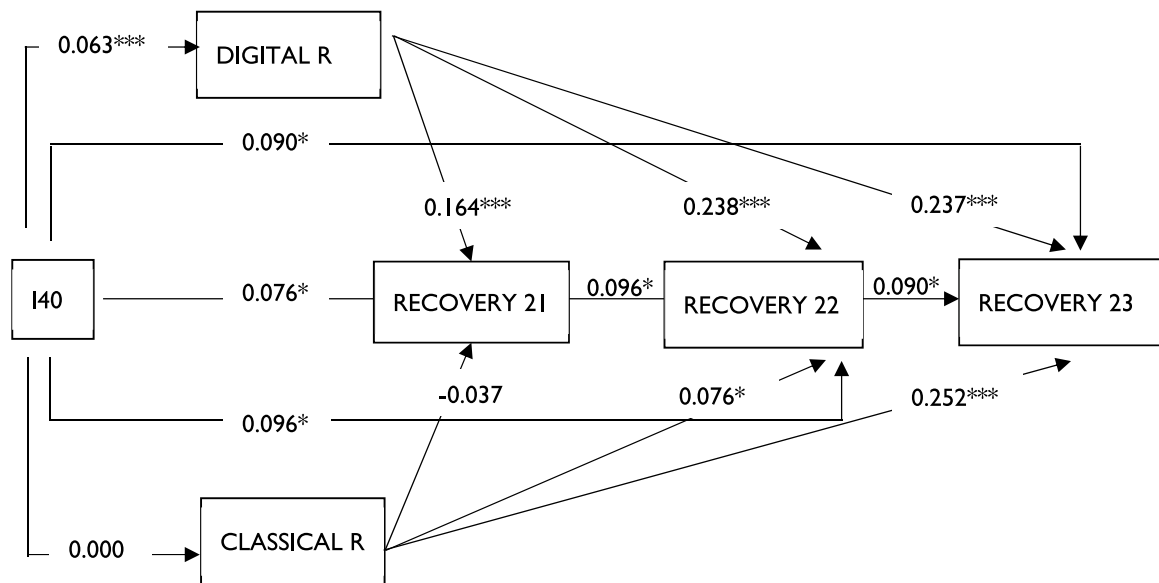
**Table 6**  
Indirect effects.

	Effect	Robust SE	LLCI	ULCI
I40 à DIGITAL R & CLASSICAL R à RECOVERY 21	0,010	0005	0,000	0020
I40 à DIGITAL R & CLASSICAL R à RECOVERY 22	0,015	0008	0,000	0030
I40 à DIGITAL R & CLASSICAL R à RECOVERY 23	0,015	0011	-0,007	0037

**Table 4**  
Correlation matrix.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. I40	1.000										
2. DIGITAL R	0.108	1.000									
3. CLASSICAL R	-0.004	0.18	1.000								
4. SKILLED WF	0.135	0.118	-0.007	1.000							
5. AGE	-0.028	0.000	-0.031	-0.022	1.000						
6. SIZE	0.227	0.087	-0.015	0.257	-0.047	1.000					
7. HIGH-TECH	0.056	0.031	-0.046	0.194	-0.014	0.184	1.000				
8. NORTH-WEST	0.022	0.037	-0.024	0.019	0.135	0.095	0.078	1.000			
9. NORTH-EAST	0.023	-0.019	-0.047	-0.035	-0.060	0.081	0.050	-0.436	1.000		
10. CENTER	-0.015	-0.035	0.039	-0.003	-0.020	-0.095	-0.060	-0.353	-0.329	1.000	
11. SOUTH	-0.039	0.015	0.043	0.020	-0.071	-0.111	-0.089	-0.323	-0.301	-0.243	1.000
VIF <sup>a</sup>	1.07	1.06	1.04	1.12	1.03	1.17	1.07	1.96	1.89	1.71	

<sup>a</sup> Calculated on the regression with RECOVERY 21 as the dependent variable.



\*, \*\*, and \*\*\* indicate that the coefficients are statistically significant at the <10%, <5%, and <1% levels, respectively.

**Fig. 3.** Results

\*, \*\*, and \*\*\* indicate that the coefficients are statistically significant at the <10%, <5%, and <1% levels, respectively.

The second research question is logically positioned in the second research stream identified in the literature. The results show that the openness to Industry 4.0 leads to a digital reorganization of firms (H2), while a classical reorganization of firms (H3) is not supported. These results partially confirm the literature stating that technological adoption must be combined with the creation of a communication, intermediation, and relationship environment (environment 4.0) through the reorganization of business activities. These results suggest that Industry 4.0 adoption influences the reorganization of businesses, increasing the use of digital business models and digital support in all activities (O'Leary, 2020; Rapaccini et al., 2020; The Economist, 2020). However, by not supporting the existence of the same relationship for classical reorganization, the results partly contrast with the existing literature (Rapaccini et al., 2020).

Third, the analysis confirms the existing literature that states that production recovery needs to be supported by transformation such as a digital or classical reorganization (Paul and Chowdhury, 2021; Rapaccini et al., 2020). The results integrate and enrich the literature on the topic through a time analysis, showing, on the one hand, that digital reorganization of firms plays a relevant role in accelerating perceived production recovery in the short term (as confirmed by hypothesis H4<sub>21</sub>). In fact, the rate of change increases in the first two years (as confirmed by hypothesis H4<sub>22</sub>), stabilizing in the third year (as confirmed by hypothesis H4<sub>23</sub>) while remaining positive and significant. On the other hand, classical reorganization of firms does not have a significant impact in the short term (as confirmed by hypothesis H5<sub>21</sub>) but has an increasing impact on the perceived production recovery in the medium term (as confirmed by hypotheses H5<sub>22</sub> and H5<sub>23</sub>). Thus, the classical reorganization of firms does not immediately depend on the openness to Industry 4.0 but, in the medium term, adapts to the transformations induced by the digital reorganization. These results seem to be in line with the Darwinian view of small firms, which suggests that SMEs follow an adaptive pattern of reorganization induced by external changes.

## 6. Conclusion

Industry 4.0 enables better recovery, defined as the ability of firms to react from an acute shock or disruption and cope with unexpected situations (Herbane, 2019; Marcucci et al., 2021). However, compared to shutdowns triggered by natural disasters and political risks, the COVID-19 pandemic has generated a dual disruptive effect (Okorie et al., 2020)—an endogenous effect generated by changes in production processes and systems and an exogenous effect generated by changes in demand and supply due to supply chain blockages.

This study focuses on the endogenous disruptions related to production levels; it empirically tests the role of Industry 4.0 on the perceived recovery of production to pre-COVID-19 levels in the short and medium term. It also evaluates the effect of two factors that mediate the relationship between openness to Industry 4.0 and the perceived production recovery. We refer to digital and classical reorganization, which may accelerate or slow down this relationship.

From a theoretical perspective, this study has two main implications. First, answering RQ1, it uses a sample of 2622 manufacturing SMEs to empirically verify a positive and significant effect of the openness to Industry 4.0 on the perceived recovery of production within 2021, 2022, and 2023. Thus, the research confirms the existing literature on the subject using a large sample of current empirical data and enriches it through a time analysis that compares the effects in the short and medium term.

Second, answering RQ2, it verifies that this relationship is significantly accelerated in the short term by digital reorganization and by classical reorganization in the medium and long term. Thus, the study enriches the literature on the topic through the results of the mediation analysis.

Critically analyzing the literature in the light of the obtained results, it is possible to confirm the findings of both streams of research related to Industry 4.0. Thus, we find that Industry 4.0 is a potential facilitator for production recovery during the COVID-19 pandemic and that this relationship might be accelerated by a reorganization of business activity.



### 6.1. Practical implications

These results can benefit managers considering the implementation of strong and sustainable business models to mitigate the effects of the pandemic. The findings suggest practical insights to managers and decision-makers to face the challenges posed by COVID-19 and identify the consequent actions and reforms that need to be implemented at the economic, social, and technological levels.

The socio-economic consequences of the COVID-19 epidemic require urgent policy responses from governments to support people and businesses (Reale, 2021). As is well known, properly designed short-, medium-, and long-term reforms by government and industry are critical to reduce distortions and increase social cohesion.

The findings and proposals of this study show that governments should reform existing economic policies to increase the use of Industry 4.0 technologies. However, as highlighted by Horváth and Szabó (2019), the lack of combination with significant changes in socio-economic systems may weaken the potential benefits of these technologies. Moreover, it is important to combine technological adoption with a considerable change in all the organizational activities, such as developing new competencies and skills, learning activities, and redefining working places and practices following the opportunities of digital transformation.

### 6.2. Limitations and future research

First, this study conducts a forecasting based on perceived production recovery. Therefore, it would be interesting to evaluate after 2021, 2022, and 2023 if the production recovery to pre-COVID-19 levels has actually been achieved. However, this analysis will not be possible until some years after the end of the ongoing pandemic.

Second, the possible influence of a latent variable related to managers' expectations of government incentives to support post-COVID-19 recovery—as outlined in the National Recovery and Resilience Plan (Piano Nazionale Ripresa e Resilienza) (PNRR, Consiglio dei Ministri, 2021)—is not considered. This is because when the survey was conducted, such incentives were not yet foreseen in Italy and Europe in general. However, there were already incentives available for the adoption of Industry 4.0 technologies—outlined in the National Transition Plan 4.0 (Piano Nazionale Transizione 4.0) (MISE, 2019). This plan, unlike the PNRR, had extremely specific requirements and relied heavily on different types of tax exemption rather than incentives comprising cash inflows and were not perceived by all firms as a useful tool to overcome the main barriers (Cugno et al., 2021). Therefore, this study represents a useful analysis to understand the relationship between Industry 4.0 and production recovery after the COVID-19 pandemic, which can then be compared with future studies considering the additional variables related to public incentives that will be available in the coming months.

Moreover, the analysis focuses on a representative sample of Italian manufacturing SMEs, and it is validated by using several control variables. However, it might be interesting to conduct a cross-country analysis comparing different industry sectors.

### Data references

This research uses a sample of 2622 manufacturing Italian SMEs from a survey conducted by Unioncamere (Italian Union of Chambers of Commerce) at the end of 2020.

### Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The research is self-financed by the Università degli Studi di Torino and Centro Studi delle Camere di Commercio Guglielmo Tagliacarne.

### Declaration of competing interest

None.

### Acknowledgments

The authors would like to thank the reviewers of Technovation for their precious suggestions.

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