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FEATURE ARTICLE

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OVERVIEW: Business leaders often consider digital technologies an enabler of new business models and market opportunities, but they often overlook their potential impact on the entire value chain. Considering three Industry 4.0 technologies—big data analytics and cloud computing, track and tracing, and simulation and modeling software—we identify the opportunities and challenges that emerge in the context of managing supply chain relationships. This study uses data from an international survey to test how these three Industry 4.0 technologies increase visibility and integration between buyers and suppliers and how they impact supply chain performance. Our results show mixed evidence: although all three technologies directly improve supply chain performance, big data analytics and cloud computing and simulation and modeling also fully support collaborative supply chain models, while track and tracing tools create more visible supply chains but are detrimental to obtaining higher process integration with suppliers. Surprisingly, buyer-supplier collaboration, in terms of visibility and integration, matters more than the technologies themselves.

KEYWORDS: Digital technologies, Supply chain, Buyer-supplier relationship, Industry 4.0

We live in a hypercompetitive environment where firms look for technological investments with fast and certain market returns (Reischauer 2018). Different methods and processes have emerged to help companies identify and exploit technological opportunities to develop new products and services (Magistretti, Dell'Era, and Verganti 2020). Digital technologies are changing the way companies operate by creating competitive environments that require frequent and radical product/service innovations (Hofmann et al. 2019). Such technological evolutions provide opportunities that go

Andrea Patrucco is an assistant professor of supply chain management in the Department of Marketing and Logistics at the Florida International University College of Business. His research interests include buyer-supplier relationships in the private and public sectors. He is one of the research leaders of the International Research Study of Public Procurement, and he actively collaborates with government organizations in the United States, such as the National Association of State Procurement Officers and the National Institute of Government Purchasing. He has published in the *Journal of Supply Chain Management*, *International Journal of Operations and Production Management*, *Supply Chain Management*, *International Journal of Production Economics*, *International Journal of Production Research*, and *Journal of Purchasing and Supply Management*. He serves as an associate editor for the *Journal of Purchasing and Supply Management*, and he is an editorial board member of the *Journal of Supply Chain Management* and the *International Journal of Logistics: Research and Applications*. apatrucco@fiu.edu

Antonella Moretto is an associate professor at the School of Management of Politecnico di Milano. At the MIP Graduate School of Business, she is associate dean for Open Programs. Her research interests include purchasing and supply management, with a focus on sustainability and supply chain finance. She has published in the *International Journal of Production Economics*, *International Journal of Production Research*, *Journal of Purchasing and Supply Management*, and *International Journal of Operations & Production Management*. She has been an executive committee member of IPSERA, the international research association of purchasing and supply management, since 2016. antonella.moretto@polimi.it

Daniel Trabucchi is an assistant professor at the School of Management, Politecnico di Milano, where he also serves as a senior researcher in the Laboratory for LEAdership, Design and Innovation (LEADIN'Lab). He is the founder of Symplatform, the international symposium on digital platforms, and a member of the Scientific Board of IDeaLs, the global research platform that explores engagement in innovation activities. His research interests include innovation management, especially digital two-sided platforms and digital services. He has published in the *Journal of Product Innovation Management*, *Technological Forecasting and Social Change*, *Internet Research*, *Research-Technology Management*, *Creativity and Innovation Management*, and others. He is also a reviewer for many of these journals. daniel.trabucchi@polimi.it

Ruggero Golini is an associate professor of general management and supply chain management at the University of Bergamo. In 2011 he received his PhD in economics and technology management with the thesis *Global Supply Chain Management in the Manufacturing Industry–Configurations, Improvement Programs and Performance*. His research interests include global supply chain management and global value chains. He is the author of more than 20 papers published in international peer-reviewed journals. He is a member of several international associations such as the European Association of Operations Management and Production and Operations Management Society. ruggero.golini@unibg.it

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beyond new product development and the user's perspective. Companies now explore whether these technologies could enhance other phases of the value creation process, particularly for the creation of more solid relationships with other supply chain partners (Erboz, Hüseyinoğlu, and Szegedi 2021). This study aims to explore if and how digital technologies can support more collaborative supply chain business models and, ultimately, improve operational performance (other than innovation performance).

Although the previous literature has largely investigated the contributions of traditional technologies to the digitalization of supply chain processes (Fawcett et al. 2011), less research exists regarding more recent and advanced technologies, particularly those that are part of the Industry 4.0 (I4.0) "revolution" (Rüßmann et al. 2015).

Companies in different industries plan to invest 5 percent of their digital revenue on the implementation of I4.0 technologies, which means over USD $900 billion per year (PricewaterhouseCoopers 2016). While some manufacturing industries, such as electronics and fast-moving consumer goods, are adopting state-of-the-art technologies and moving along the supply chain 4.0 continuum, other industries are still lagging behind, and the diffusion rate of these tools has been much lower than anticipated. Empirical studies on supply chain I4.0 technology adoption identify internal organizational challenges and external lack of cooperation with supply chain partners as the two most relevant barriers to technology implementation and diffusion in the supply chain (Hofmann et al. 2019; Hahn 2020; Erboz, Hüseyinoğlu, and Szegedi 2021).

To be successful, I4.0 requires supply chains to do more than simply adopt modern technologies and engage in capability development. Companies must also transform their business models and network structures. BJC Healthcare, Bosch, Volkswagen, DHL, Fast Radius, and General Electric are only a few examples of companies that have successfully ridden the wave of I4.0 technologies by changing their supply chain operational model (AMFG 2019). These examples show that digitally driven change in the supply business models requires a redesign of the relationships between supply chain actors (particularly with suppliers) to orient them toward more collaboration to exploit the benefits of the new technologies and maximize their impact on supply chain performance (Ivanov and Dolgui 2020).

We aim to provide more empirical evidence on the role that I4.0 technologies have in strengthening the relationship between buyers and suppliers and, ultimately, improve supply chain performance. In our study, we aimed to answer the following research question: How do I4.0 technologies help to increase visibility and integration in buyer-supplier relationships and improve supply chain performance?

How Technologies Support New, Collaborative Supply Chain Business Models

To explore how technologies enhance collaboration in supply chains, we discuss the various types of collaboration in buyer-supplier relationships, introduce the concepts of visibility and integration, and highlight the most promising technologies to enhance the collaboration.

Collaboration in Buyer-Supplier Relationships

In supply chain collaboration, two or more autonomous firms work together to plan and execute supply chain operations to leverage joint resources and knowledge and provide substantial benefits and advantages for all the partners involved (Cao and Zhang 2011). Over the last two decades, firms across all industries have significantly increased collaboration initiatives with (strategic) suppliers (Soosay and Hyland 2015) to build a supply network (and supply chain) aligned with continuously evolving markets.

Collaboration with suppliers can be designed at different levels. Wiengarten and Longoni (2015) distinguish supply chain collaboration at two levels:

1. *Visibility*, the first level, includes all the investments made to increase the degree of real-time information sharing between the buyer and supplier (Caridi et al. 2014).
2. *Integration*, the second level, refers to the joint decision-making and execution of supply chain processes typically carried out independently (Flynn, Huo, and Zhao 2010).

Visibility is usually recognized as a prerequisite for integration; together they represent strategic actions to build a world-class supply network, characterized by complementary knowledge, mutual understanding of needs, and trust (Liu et al. 2020).

Although time-consuming, collaborative buyer-supplier relationships have been proven to help actors at different levels of the supply chain achieve superior performance. In fact, collaborative relationships between buyers and suppliers can help firms share risks, access complementary resources, reduce transaction costs, and boost productivity, while improving profit performance and competitive advantage over time (Narayanan, Narasimhan, and Schoenherr 2015; He et al. 2017).

Technologies' Role in Supply Chains

Technologies have a clear role in improving supply chain management through a phenomenon generally called supply chain digitalization (Gunasekaran, Subramanian, and Papadopoulos 2017; Gupta et al. 2020).

Researchers have studied extensively the use of digital technologies at the supply chain level, particularly traditional technologies such as radio frequency identification (RFID) (Balocco et al. 2011), enterprise resource planning (Green, Whitten, and Inman 2007), and electronic data interchange (Choe 2008). Yet researchers do not yet know fully the contributions of most recent and innovative technologies. Meier (2016) identifies several digital technology trends that can improve supply chain management. Three technology clusters seem particularly promising from a supply chain

Three technology clusters seem particularly promising from a supply chain relationship management perspective: big data analytics and cloud computing, track and tracing, and simulation and modeling.

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Big data analytics and cloud computing could support machine-enabled decisions with minimal or no human intervention, thus improving the timing and the depth of these decisions, especially in the case of shared decision processes (Waller and Fawcett 2013; Makris, Hansen, and Khan 2019). The Internet of Things (IoT) enables big data analytics and cloud computing and allows real-time data collection and information sharing, making businesses act in a predictive manner instead of reacting to the challenges of a complex and volatile market (Haddud et al. 2017). These benefits help supply chain partners to significantly improve their operational performance through effective management of their inventory and production plans (Lee and Lee 2015).

Supply chains have used track and tracing technologies for several decades, including RFID since the 1990s. More advanced technologies, such as wireless sensor networks, machine-to-machine systems, and mobile apps (Li et al. 2017) are increasingly common. These tools make each individual item trackable and traceable, and generate highly transparent supply chains, where the location of all the elements could be determined at any point in time (Yan et al. 2016).

Finally, the complexity of manufacturing and logistics processes can benefit from the use of simulation and modelling software. These technologies can help to prevent (or solve) problems that might affect multiple actors in the supply chain, such as excess product volumes that quickly lose value; response to changing client requests and/or supplier availability; optimization of shipments; and assurance of complete deliveries (Kache and Seuring 2017).

Technologies, Supply Chain Collaboration, and Performance: A Missing Link?

Supply chains that can respond and adjust quickly to this fast-technological growth achieve more significant benefits and greater competitive advantages in modern business environments (Narayanan, Narasimhan, and Schoenherr 2015).

Several studies have demonstrated the contribution of technologies for more effective supply chain management. Researchers emphasize benefits such as improvements in operational performance (Hsin Chang, Tsai, and Hsu 2013; Bruque, Moyano, and Maqueira 2016; Erboz, Hüseyinoğlu, and Szegedi 2021) and achievement of more strategic supply chain objectives such as agility and resilience (Tarafdar and Qrunfleh 2017; Ivanov and Dolgui 2020). Researchers have also discussed how the use of digital technologies is a driver of stronger supply chain collaboration (Gunasekaran, Subramanian, and Papadopoulos 2017; Cui et al. 2020) and an effective lever to enhance collaboration benefits (e.g., Vanpoucke, Vereecke, and Muylle 2017; Manuel Maqueira, Moyano-Fuentes, and Bruque 2018).

The literature has separately recognized I4.0 technologies as a collaboration enabler and performance enhancer, but research studying this dual role concurrently is missing. We aim to fill this gap by testing the relationships in a new research model (Figure 1). First, we verified that the use of specific I4.0 technologies—that is, big data analytics and cloud computing, track and tracing, and simulation and modeling—positively impacts supply chain performance, in terms of quality, cost, time, and flexibility. Then we explore the role that supply chain collaboration, in terms of visibility and integration levels, plays. In other words, does using these three digital technologies in a more or less collaborative supply chain—that is, in buyer-supplier relationships with a higher/lower level of visibility or integration—impact supply chain performance?

Method

To test the model, we used data collected between 2017–2018 via an online survey questionnaire specifically designed for

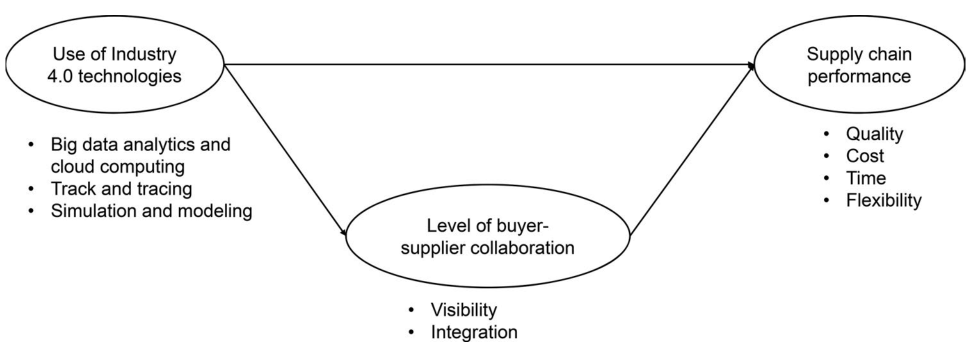

FIGURE 1. Research model

this study. To design the questionnaire, the research team conducted exploratory interviews and focus groups during August–September 2017 that involved supply chain managers from companies in the construction, oil and gas, food, pharmaceutical, chemical, and plastic industries. We asked participants to rank and discuss the most important I4.0 technologies for the implementation of collaborative supply chain business models.

Based on this preliminary qualitative information, we identified three classes of technologies as strategic: big data analytics and cloud computing (including the use of artificial intelligence to implement big data analytics), track and tracing technologies (including more traditional technologies such as RFID and QR codes), and simulation and modelling (focusing on 3D printing and technologies adopted to support manufacturing activities). We built a survey based on questions and measures used in previous studies which were adjusted following the insights provided by practitioners (Table 1).

The ideal survey respondents were supply chain professionals working in the areas of purchasing, operations, and/or logistics. Given the value of cross-national research in supply chain management (Cheung, Myers, and Mentzer 2010), to increase the validity of our findings we opted for a multi-country sample. We designed a convenient sample of 1,044 manufacturing companies with headquarters in different European and North and South American regions, starting from a database of contacts that the research team

TABLE 1. Construct measures, validity, and reliability

Construct	Factor Loadings	Average Variance Explained	Composite Reliability
Big Data and Cloud Computing Technologies		54.83%	0.828
—We use cloud computing technologies to collect data	0.711		
—We use advanced data analysis software (big data analytics)	0.863		
—We use cloud computing technologies to analyze data	0.800		
—We use cloud computing technologies to share data and information with supply chain actors	0.923		
Track and Tracing Technologies		55.25%	0.786
—We use RFID technology to track the products in real time along the supply chain	0.671		
—We use Bluetooth technology to track the products in real time along the supply chain	0.847		
—We use a QR code to track the products in real time along the supply chain	0.699		
Simulation and Modelling		53.14%	0.771
—We use 3D printing for managing production activities	0.644		
—We use advanced simulation software for managing production activities	0.812		
—We use 3D modeling software for modeling and redesigning production activities	0.721		
Buyer-Supplier Visibility		50.28%	0.752
—Our suppliers share with us information about inventory and demand forecast	0.715		
—We share information about inventory and materials requirements planning with our suppliers	0.716		
—The information from and to the suppliers are shared in real time	0.697		
Buyer-Supplier Integration		66.36%	0.855
—We collaborate with suppliers in the development of new products/services (e.g., early supplier involvement)	0.819		
—We collaborate with suppliers to reduce the time-to-market for the launch of new products/services	0.778		
—We collaborate with suppliers to increase the level of integration of operations (e.g., VMI, Just-in-time, etc.)	0.846		
Supply Chain Performance		54.13%	0.825
—Our supply chain can deliver product to customer with the expected level of quality (e.g., zero-defects)	0.689		
—Our supply chain can minimize the total logistics costs	0.709		
—Our supply chain can deliver products/services on time	0.757		
—Our supply chain can respond and solve problems quickly	0.784		
Chi/df		1.81	
CFI		0.945	
TLI		0.923	
RMSEA		0.056	

has developed. We received 378 questionnaires with completion of 75 percent or higher (which corresponds to a raw response rate of 36 percent). After removing responses with missing values on critical items for the study, we obtained a final sample of 286 usable responses (Table 2).

The relationships in the research model were statistically tested using Covariance-based Structural Equation Modelling (CB-SEM), a common method used for survey-based research. As a first step, we performed Confirmatory Factor Analysis (CFA) to confirm validity and reliability of constructs. Then, we tested the structural model through Structural Equation Modelling (SEM). We evaluated the model fit using the chi-square goodness-of-fit statistic and the use of other absolute or relative fit indices (Bagozzi and Yi 1988).

We tested the research model in three steps. Model 1 verifies the direct relationship between the I4.0 technologies and supply chain performance. Model 2 and Model 3 test the mediation effect of the level of buyer-supplier collaboration in terms of visibility (Model 2) and integration (Model 3), respectively, exploring how these two types of collaboration impact the role I4.0 technologies have on supply chain performance.

TABLE 2. Sample characteristics

	Frequency	*%*
Country		
Europe	133	*49.6%*
North America	126	*47.0%*
Central and South America	9	*3.4%*
Industry		
Process manufacturing	146	*54.4%*
Discrete manufacturing	122	*45.6%*
Respondent area		
Purchasing	114	*39.9%*
Supply Chain	69	*24.1%*
Operations/Manufacturing	54	*18.9%*
Logistics	49	*17.1%*
Employees		
Small (< 100)	3	*1.0%*
Medium (100–250)	54	*18.9%*
Big (251–500)	80	*28.0%*
Very Big (> 500)	149	*42.1%*

Results

We present the results Model 1 (Figure 2), Model 2 (Figure 3), and Model 3 (Figure 4).

First, we verified the basic assumption (supported by previous literature) that I4.0 technologies positively impact supply chain performance. By testing Model 1, we can see that the three classes of technologies included in the research model all have a positive and significant relationship on supply chain performance. A more intense use of big data analytics and cloud computing (ß = 0.292, $p<0.001$), track and tracing (ß = 0.228, $p<0.01$), and simulation and modeling software (ß = 0.201, $p<0.05$) enhance the supply chain's ability to solve problems, deliver products and/or services on time, meet customer quality standards, and, overall, optimize logistics costs.

Given this starting point, we wanted to explore how the two collaboration types, visibility and integration, affect these technologies' impacts on supply chain performance.

In Model 2, we aimed to explore visibility's effect in the buyer-supplier relationship regarding how I4.0 technologies impact supply chain performance. Although all three of the I4.0 technologies are positively related to buyer-supplier visibility, we found that only the use of track and tracing technologies maintains a significant and positive relationship with supply chain performance (ß = 0.177, $p<0.05$). By contrast, for big data analytics and cloud computing (ß = 0.273, $p<0.001$) and simulation and modeling software

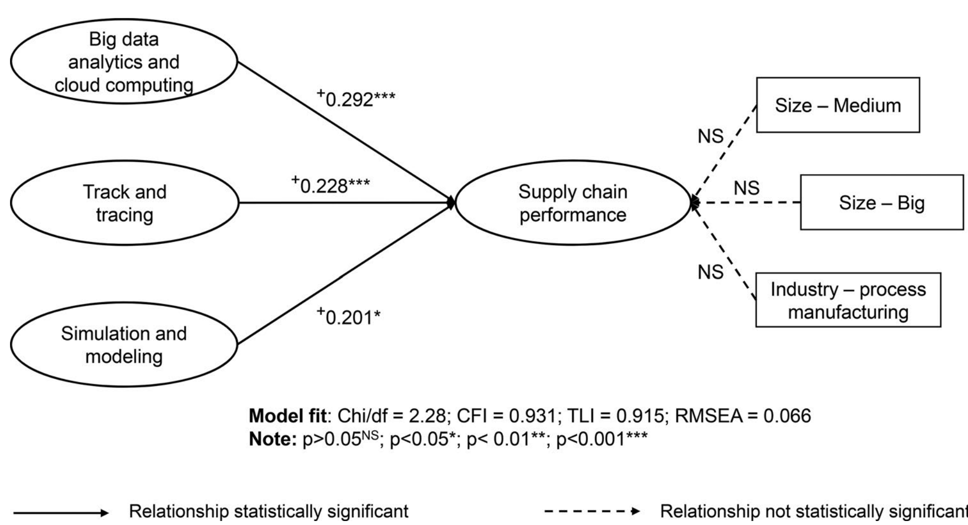

FIGURE 2. Model 1 testing results (without mediators)

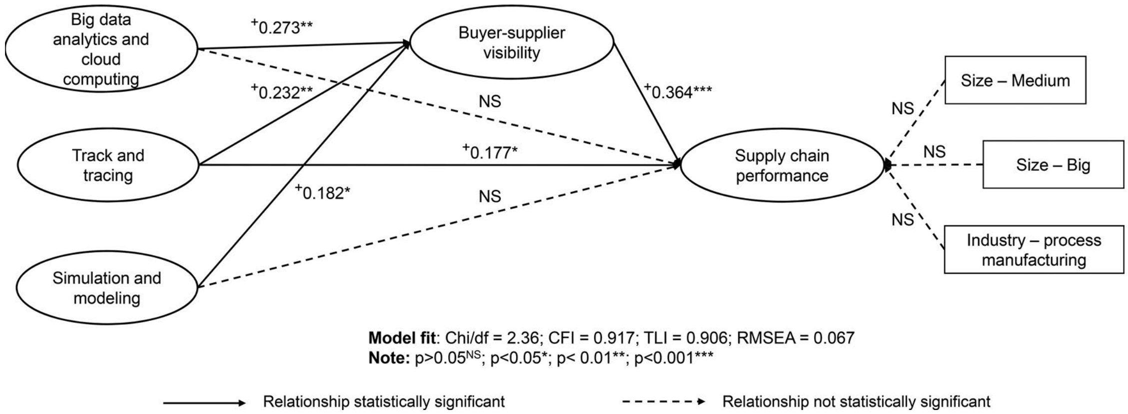

FIGURE 3. Model 2 testing results (with visibility as mediator)

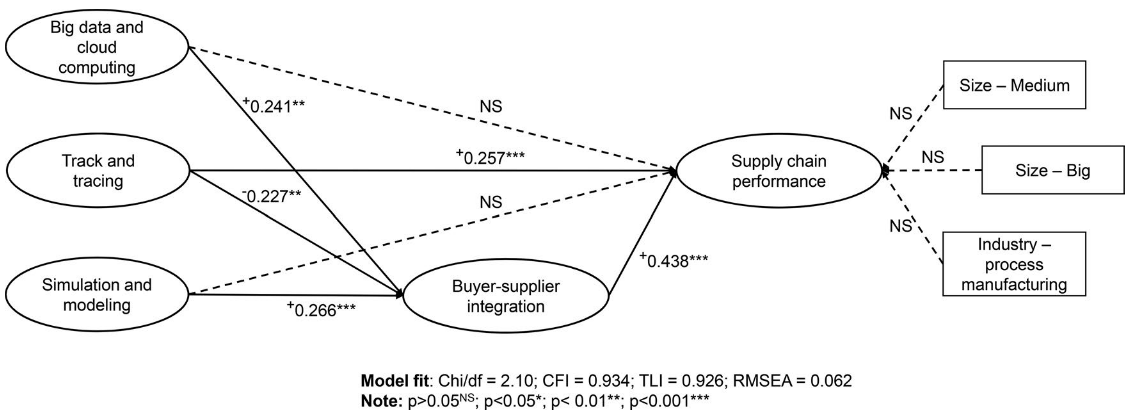

FIGURE 4. Model 3 testing results (with integration as mediator)

(ß = 0.182, $p < 0.05$), the positive effect in Model 1 is completely absorbed by the positive association with the buyer-supplier visibility variable which, in turn, positively impacts supply chain performance (ß = 0.364, $p < 0.001$). In other words, supply chains with a higher level of visibility in the buyer-supplier relationship receive more benefits from the impact of big data analytics and cloud computing and simulation and modeling software.

In Model 3, we aimed to explore integration's effect on the buyer-supplier relationship regarding how I4.0 technologies impact supply chain performance. While big data analytics and cloud computing (ß = 0.241, $p < 0.01$) and simulation and modeling software (ß = 0.266, $p < 0.001$) are positively related to buyer-supplier integration, for track and tracing we have a significant but negative relationship (ß = –0.227, $p < 0.01$). Track and tracing is also the only technology that maintains a positive relationship with supply chain performance (ß = 0.257, $p < 0.001$). Again, for big data analytics and cloud computing and simulation and modeling software, the positive effect in Model 1 is completely absorbed by the buyer-supplier integration variable which, in turn, positively impacts supply chain performance (ß = 0.438, $p < 0.001$). In other words, supply chains with a higher level of integration in the buyer-supplier relationship receive more benefits from the impact of big data analytics and cloud computing and simulation and modeling software.

For track and tracing technologies, the situation is definitely different. These technologies still have a positive impact on performance, but their presence tends to reduce the collaborative efforts in terms of integration in the buyer-supplier relationship.

We verified the robustness of the mediation effects using the Baron and Kenny (1986) method, together with the bootstrapping analysis of confidence intervals for indirect effects (see "Verifying the Robustness of the Mediation Effect" on page 54).

We wanted to explore how the two collaboration types, visibility and integration, affect these technologies' impacts on supply chain performance.

TABLE 3. Summary of the results

	Buyer-Supplier Visibility	Buyer-Supplier Integration	Supply Chain Performance		
			Without Mediators	With Buyer-Supplier Visibility as Mediator	With Buyer-Supplier Integration as Mediator
Impact of the use of cloud and big data technologies on…	Positive	Positive	Positive	Absent (positive mediation)	Absent (positive mediation)
Impact of the use of track and tracing technologies on…	Positive	Negative	Positive	Positive (mediation effect not significant)	Positive (partial negative mediation)
Impact of the use of simulation and modeling technologies on…	Positive	Positive	Positive	Absent (mediation effect not significant)	Absent (positive mediation)

We summarize the main results of the study and their interpretation (Table 3).

Discussion

Our study goes beyond the analysis of the positive association between I4.0 technologies and supply chain performance (a consolidated result in the literature). It concludes that the benefits of the adoption of innovative technologies combines positively with high levels of visibility and integration within buyer-supplier relationships. Collaborative relationships, in fact, are designed themselves to improve supply chain performance, and this impact can be enhanced through a synergistic use of I4.0 technologies to support the collaboration. In other words, the adoption of digital technologies in combination with existing visibility and integration investments matters more than simply adopting I4.0 technologies because the combination allows companies to maximize the impact on supply chain performance.

Our finding aligns with results from previous supply chain management literature (Hsin Chang, Tsai, and Hsu 2013), but it elaborates on this positive relationship for the three classes of digital technologies included within the same model.

Compared to existing results related to the role of I4.0 in supply chains, our model represents the first attempt to test the mediation effect of buyer-supplier visibility and integration. Although previous literature highlights how digital technologies improve the level of coordination and visibility in the supply chain (Cui et al. 2020), our study analyzes the synergies between collaboration efforts and digital tools for specific categories of I4.0 technologies using international survey data.

Big Data Analytics and Cloud Computing

The main value of big data analytics and cloud computing technologies is that they facilitate more collaborative buyer-supplier relationships, not that they directly improve supply chain efficiency and performance. This result aligns with previous studies (Bruque et al. 2016), which argue that internet-based IT infrastructure and real-time analysis of structured and non-structured data effectively support supply chain collaboration, as they increase the availability of knowledge and information for the supply chain actors; make supply chains more transparent and less complex, enabling more reliable decision-making; optimize supply chain operations; and focus improvement initiatives. In

Verifying the Robustness of the Mediation Effect

To further verify the robustness of the mediation effect of the two mediators included in Model 2 and Model 3 on the relationship between I4.0 technologies and supply chain performance, we applied the Baron and Kenny (1986) method, together with the bootstrapping analysis of confidence intervals for indirect effects.

For buyer-supplier visibility, a mediation effect is present only for big data analytics and cloud computing technologies, for which the indirect effect is the only one significant (ßindirect = 0.099, p < 0.05), and the confidence interval calculated through bootstrapping does not contain the zero. Considering that, in this mediated model, the direct effect of big data analytics and cloud computing on supply chain performance is no more significant, we can conclude that the positive effect on supply chain performance from Model 1 is entirely (positively) mediated by the presence of buyer-supplier visibility.

For buyer-supplier integration, a mediation effect is present for all the technologies, as the indirect effects are all significant, and the confidence interval calculated through bootstrapping does not contain the zero.

This mediating effect is positive for big data analytics and cloud computing ($ß_{indirect}$ = 0.105, $p < 0.05$) and simulation and modeling ($ß_{indirect}$= 0.116, $p < 0.05$), while it is negative for track and tracing ($ß_{indirect}$ = –0.099, $p < 0.05$).

These results show that, although the three classes of I4.0 technologies studied potentially contribute to positively impact supply chain performance:

- The positive effect of big data analytics and cloud computing and simulation and modeling technologies from Model 1 is entirely (positively) mediated by the presence of buyer-supplier integration (as the direct effect is no more significant); and
- The positive effect of track and tracing from Model 1 is partially (negatively) mediated by the presence of buyer-supplier integration (as the direct effect is still significant, while the total effect is positive, and significant).

None of the control variables included in the models (company size and type of manufacturing industry) are significantly related to supply chain performance.

sectors like construction and oil and gas where purchasing is particularly key for supply chain activities, these technologies have been adopted exactly with this purpose in mind (Patrucco, Ciccullo, and Pero 2020). The big data analytics and cloud computing software used in these supply chains maximize the possibility of collecting, analyzing, and sharing information, making processes more transparent, more manageable, and less costly.

It is strategically important for companies to redesign their supply chain business models if they want to get the most from these technologies. Using these digital technologies can increase the supply chain performance, but without efforts to enhance the level of collaboration in the buyer-supplier relationship, in terms of enabling higher visibility or better integration, the impact of these technologies will be limited. This result also supports the idea that introducing these technologies should not be an individual effort of a focal company, but a collective effort with other supply chain actors to improve the commitment of buyers and suppliers (Manuel Maqueira, Moyano-Fuentes, and Bruque 2018).

Simulation and Modeling Technologies

Similar to big data analytics and cloud computing, simulation and modeling technologies are positively related to supply chain performance. Simulation and modeling technologies help to increase buyer-supplier visibility and integration in collaborative supply chain business models; however, only integration can amplify the effect of these technologies. Technologies always improve, but the impact of these technologies on supply chain performance is significantly higher for supply chains with high levels of integration.

The use of virtual applications to simulate manufacturing and logistics activities at any time and place allows companies to anticipate, identify, and manage potential issues, thus enabling both higher efficiency and capability to prevent quality and service problems (Lee and Lee 2015). For example, these technologies could help to identify several manufacturing constraints (such as capacity limitations, bottlenecks, scrap, machine failure), generate alternative product configurations (such as through 3D printing), and simulate alternative options of supply chain design. Although these technologies help increase visibility and transparency in the supply chain, their value is mostly enhanced in situations of high process integration with strategic suppliers.

In industries such as pharmaceuticals and aerospace, where digital technologies are widely adopted, the use of simulation and modelling software supports the optimization of supply chain flows (by identifying improvements in production and logistics systems) and enables the collaborative design of materials and components with suppliers—thus being a driver of even higher process integration and alignment (Tarafdar and Qrunfleh 2017). This is an excellent example that illustrates why this type of collaboration—rather than the technologies themselves—positively impacts supply chain performance.

Tracking and Tracing

For track and tracing, the situation is different yet. In the context of traditional supply chain business models, the use of tracking and tracing technologies positively impacts supply chain performance, and this direct effect remains consistent in supply chains that have a high level of buyer-supplier collaboration. Although track and tracing technologies help increase the level of buyer-supplier visibility, the buyer-supplier collaboration does not enhance how the technology improves the supply chain's performance. To assess the benefits that the introduction of these technologies can provide, companies can look directly at the changes in supply chain performance given the existence of positive and direct relationships independent from the level of visibility. Track and tracing technologies can be implemented at the firm level without needing to rely on collaborative supply chain business models to improve supply chain performance. While track and tracing tools can increase the level of visibility along the supply chain, their primary goal is to provide reliable and timely data that can directly improve supply chain performance (in terms of optimizing flows and inventory, detecting quality problems, and increasing responsiveness in delivery). In the construction sector, for example, the use of QR codes to locate cargos of materials coming from suppliers' plants to the project site can help the construction company optimize the delivery cycle and quality control (Patrucco, Ciccullo, and Pero 2020). Companies can rely on more meaningful pieces of information (thus increasing the visibility), but the use of these technologies can still guarantee significant performance improvement without having specific collaboration efforts in place with suppliers.

Although surprising, this result can be explained by considering the fact that track and tracing reduces the need to exploit collaboration beyond visibility, as a perfect sharing of the flows limits the need to have a real integration in the process and in the activities performed. Thanks to a full visibility of the flows, buyers and suppliers are already orchestrating their processes without really integrating them. In several manufacturing contexts such as electronics, food, and clothing, tools such as RFID, smart sensors, and real-time track and tracing software reduce the execution effort for production and logistics activities. Also, the tools are usually implemented to reduce the need for formal coordination and integration in the supply chain, due to the ability to monitor in real time the status and the position of items in the supply

It is strategically important for companies to redesign their supply chain business models if they want to get the most from big data analytics and cloud computing technologies.

chain (Li et al. 2017). The increased visibility these technologies provide implicitly reduces the need for additional support through other forms of collaboration (such as process integration). However, designing and implementing track and tracing systems requires time and resources, which results, at least initially, in a possible deterioration of supply chain performance with regard to cost and time (Chong et al. 2015).

Managerial Implications

Our results show that at a strategic level digital technologies represent a driver of business model innovation (Rayna and Striukova 2016). At the operational level they can enhance collaboration and supply chain performance (Soosay and Hyland 2015). Technologies enable seamless supply chains and allow each actor in the network to be more agile in responding to customers' changing needs by making available undistorted and up-to-date data at different nodes in the supply chain.

Digitalization and technologies have evolved to create more connected and collaborative networks. This study represents the first attempt to bring together different types of technologies and analyze them in terms of their indirect (through collaboration) and direct effect on supply chain performance. Managers can use the key findings from our study to understand better why they should introduce specific I4.0 technologies and what benefits they may derive from doing so. Practitioners can also understand the role of visibility and integration, respectively, in facilitating collaboration in buyer-supplier relationships and in improving supply chain performance. For example, a company within a supply chain looking to increase its visibility level with suppliers may want to introduce big data analytics and cloud computing and track and tracing technologies, because they have the highest synergies with this type of buyer-supplier collaboration. By contrast, a company operating in more integrated supply chains should prioritize investments in big data analytics and cloud computing and simulation and modeling tools since track and tracing technologies may hinder previous efforts in terms of integration.

Innovative players will take advantage of new digital technologies, not simply to share information in a static way or to enhance their business models, but also to dynamically plan and execute their operations collaboratively, thus enhancing the overall coordination and alignment within the supply chain. I4.0 has taken this opportunity for collaboration to the next level: tools such as IoT-enabled big data analytics and cloud computing, advanced track and tracing, and simulation and modeling software are creating more and more opportunities for supply chain collaboration (Erboz, Hüseyinoğlu, and Szegedi 2021).

Study Limitations

This study should be considered a starting point for future research and practice. Digital technologies have many complex implications for organizations, and practitioners must assess their impact on the entire organizational ecosystem, not merely on the final performance, as we demonstrated with the role of visibility and integration in the buyer-supplier relationship. Technologies continue to evolve and offer new opportunities that should be considered carefully. Blockchain, for example, is emerging as a game changer in collaboration efforts and offers its own opportunities to increase visibility and integration. We did not include blockchain in our study, but other recent studies show how it is changing the platform paradigm by disintermediating relationships between parties (Trabucchi et al. 2020). Current research cannot yet fully answer the question, what if blockchain could be the key to enhancing the power of I4.0 technologies in the supply chain? This study can help frame future research regarding collaboration and I4.0 technologies.

Conclusion

Our study can be summarized simply: buyer-supplier visibility and buyer-supplier integration matters more than the digital technologies used. Visibility and integration can enhance the effects digital technologies have on supply chain performance. Digital technologies are useful beyond generating new business models, improving performance, and reducing costs. I4.0 technologies can profoundly impact organizations, and companies need to carefully consider how they use them, given that high levels of buyer-supplier collaboration can enhance the technologies' abilities to improve supply chain performance.

ORCID

Andrea Patrucco http://orcid.org/0000-0002-9367-1561
Daniel Trabucchi http://orcid.org/0000-0003-1290-8043

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