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Industry 4.0 digital technologies and international performance: The role of family management in Italian firms

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ABSTRACT

This paper advances the international business literature by providing robust empirical evidence on how the adoption of Industry 4.0 digital technologies affects firms' international performance. Drawing on panel data of Italian firms and a matched Difference-in-Differences design, we show that only information digital technologies – such as big data analytics and the Internet of Things – positively impact international performance, while robotics does not. Using a dynamic capabilities perspective, we argue and quantitatively test that digitalisation is most effective if paired with high-quality managerial structures, that is, when external, non-family professionals manage firms. A complementary qualitative inquiry of five case studies further illustrates the mechanisms through which external managers enable firms to capture the strategic value of digital investments in international markets. By isolating the role of distinct digital technologies and governance structures, the study offers new insights into the micro-foundations of digital-enabled internationalisation.

1. Introduction

Digitalisation, or the adoption and integration of digital technologies in business processes (Verhoef et al., 2021), is a relevant factor in shaping performance in international markets (Dagnino and Resciniti, 2021; Lee et al., 2019; Ruigrok et al., 2007; Werner, 2002; Westerlund, 2020). However, significant room exists for developing the topic in international studies (Bergamaschi et al., 2021; Dagnino and Resciniti, 2021). For example, empirical assessments of the direction of causality are still scant; few researches update the analytical framework to the latest digital technologies and a vast amount focus on the online channel; most papers cannot distinguish between different technologies adoption and exploit relatively small datasets (Bergamaschi et al., 2021; Denicolai et al., 2021; Nunes et al., 2024). Moreover, there is space to investigate the moderating factors of the digitalisation-internationalisation nexus: the extent and effectiveness of such a nexus depend on a series of contingency factors, especially in light of the new digital technological developments of the Industry 4.0 (I4.0) era (Rüßmann et al., 2015; Strange and Zucchella, 2017), whose implementation increases the complexity of the firm's business processes and models.

The presence of various foreign markets obliges firms to face substantial economic uncertainties, whose sources are market and institutional diversity, translating into higher information processing requirements (Fan et al., 2017; Li et al., 2020; Premkumar et al., 2005). Moreover, internationalisation induces several managerial tensions (Ciabuschi et al., 2015; Galbraith, 1974; Sengul and Gimeno, 2013; Tushman and Nadler, 1978) such that between global cross-border knowledge integration and local market responsiveness (Subramaniam, 2006; Zhao et al., 2021). Adopting and integrating digital technologies in business processes is expected to help fulfil such needs that arise from the hardship of managing diverse international markets (Drori et al., 2024; Dutot et al., 2014, 2022) and relax the strategic tensions by easing coordination and control of global value chains (Kano et al., 2020; Rangan and Sengul, 2009; Tippmann et al., 2012; Tushman and Nadler, 1978; Verbeke and Kano, 2016).

In this paper, we posit that the adoption of I4.0 digital technologies (I4.0 DTs), such as the Internet of Things (IoT), big data analytics, augmented reality and advanced robotics (Rüßmann et al., 2015; Strange and Zucchella, 2017), can contribute to managing the tensions ignited by internationalisation. Moreover, we show that the quality of management has a significant positive moderation effect on the linkage between such technological adoption and internationalisation (Agostini

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and Filippini, 2019; Parent and Reich, 2009; Peng and Jia, 2023). Inspired by the literature on upper echelons theory (Hambrick and Mason, 1984) and dynamic capabilities (Teece, 2007; Teece et al., 1997), we argue that a crucial component for a successful digital investment is a top management team (TMT) with external managers instead of only family managers. More specifically, managerial teams that include externally sourced managers with diversified professional trajectories – beyond the confines of a single-family firm – are better equipped to seize and pursue the opportunities brought by I4.0 DTs on the international market expansion and to transform the organisational structure of the firm accordingly (Ceipek et al., 2021; Chen et al., 2023; Peng and Jia, 2023).

The necessary data to provide an in-depth analysis of the interplay between I4.0 DTs adoption and the intensity and success of internationalisation strategies is very rare. The present research sets a discontinuity with previous studies on the topic because it exploits a rich firm-level survey with national representativeness across sectors and firms' sizes in Italy, namely the *Rilevazione Imprese e Lavoro* (RIL), and applies an empirical methodology capable of disentangling the role of different I4.0 DTs and polishing such effect by sources of bias (Cirillo et al., 2023). Five exploratory case studies are then used to identify the role of non-family managers in using I4.0 DTs to expand the firm's market presence in foreign markets.

The Italian context is particularly suitable for investigating the contraposition between family management and top management external to the family. Indeed, with respect to other European countries, Italy has a considerable share of family businesses (Faccio and Lang, 2002) run by a Chief Executive Officer (CEO) belonging to the family (Bugamelli et al., 2018).

Our research contributes to the international studies literature as follows. First and foremost, we enrich the literature with an empirically robust, micro-funded and generalisable quantitative analysis to support the hypothesis that investing in digitalisation through I4.0 DTs adoption enhances international performance, a hypothesis previously stated but seldom tested robustly (Bergamaschi et al., 2021; Cassetta et al., 2020; Dagnino and Resciniti, 2021; Hervé et al., 2020; Zheng et al., 2023; Zhou and Xu, 2024).

Moreover, the data's level of detail enables us to separately estimate the impact of information (big data analytics, IoT and augmented reality) versus production (advanced robotics) I4.0 DTs. Even though we hypothesise that information and production I4.0 DTs positively impact international performance, we find affirmative evidence for adopting information technologies only and suggest that such a result might derive from information technologies implementation demanding a more intense organisational restructuring (Colombari et al., 2023) and more developed digital strategies. We corroborate this insight by showing that the effect of I4.0 DTs adoption is stronger when the firm is run by non-family, rather than family, managers, whose dynamic capabilities endowment plays a significant role.

2. Theoretical background

2.1. The linkage between digitalisation and internationalisation

Firms amidst an internationalisation process face higher information processing needs. When firms match such needs with adequate information processing capacities, such as those enabled by Information and Communication Technologies (ICTs) first and I4.0 DTs nowadays, they experience better performances (Drori et al., 2024; Dutot et al., 2014; Kearns and Lederer, 2004; Tushman and Nadler, 1978; Vial, 2019). The promises of I4.0 DTs are manifold and stem from their recombinatorial power. These pervasive technologies enable more granular monitoring of products and production processes and rely on virtualisation logics that support accurate decision-making. Digital architectures are modular, promote interoperability between different systems, and provide access to computing power and software – such as AI algorithms – without requiring high fixed costs. Recent studies emphasise that the main challenge has shifted from the mere adoption of technology to its integration with organisational processes and its effective use in enabling more agile business models (Denicolai et al., 2021; Kessler et al., 2022; Kinkel et al., 2023; Verhoef et al., 2021).

Information processing needs induced by internationalisation. Primary sources of increased information processing needs for firms with an international geographical scope are market diversity and the need to establish a local value chain in the foreign market. More specifically, internationalisation is related to the need to adapt the product and operations to multiple local market specificities, going from customer preferences to competitive dynamics and the institutional environment (Ciabuschi et al., 2015; Premkumar et al., 2005). For example, a relevant market specificity is the regulatory framework. Compliance with international regulations such as data protection laws, market certifications and trade policies necessitates sophisticated information processing systems (Eden and Miller, 2004; Hitt et al., 2006). Firms must collect and share substantial information with partners to appropriately design product requirements and specifications that meet country-specific standards.

Furthermore, coordinating activities across geographically dispersed units involves processing information related to logistics, supply chains, and resource allocation choices. Effective integration of global operations depends on real-time information flows and decision-making processes (Bartlett and Ghoshal, 1998; Bode and Wagner, 2015). Hence, firms must process large volumes of data to tailor internationalisation strategies effectively (Doz and Kosonen, 2010; Gaur et al., 2011).

Information processing needs induced by internationalisation generate managerial tensions. The elevated information processing needs associated with internationalisation generate a strategic tension that affects how firms manage product development and operations.

First, internationalisation generates tension between centralisation and decentralisation in the decision-making and the information processing required in each value chain stage (Galbraith, 1974; Rangan and Sengul, 2009; Tippmann et al., 2012; Tushman and Nadler, 1978). Such tension is linked inherently with another one between global cross-border knowledge integration, which is beneficial for product development, and local market responsiveness, which is crucial for adapting to market-specific needs (Subramaniam, 2006).

Moreover, internationalisation entails substantial transaction costs generated by information asymmetries and costs intrinsic to the relationship with (geographically and culturally) distant suppliers and clients (Goldfarb and Tucker, 2019). Managing relationships with local suppliers, customers, and partners is critical, and these capabilities are often tacit or difficult to codify (Bailey et al., 2012; Lanzolla et al., 2021). In other words, internationalisation raises the demand for proximity for both knowledge-intensive (such as knowledge transfer and value co-creation) and production activities. Effective governance of global value chains requires balancing the need for proximity with the capabilities to manage these relationships efficiently (Gereffi et al., 2005).

How information and production I4.0 DTs help address the managerial tensions induced by internationalisation. Information (big data analytics, IoT and augmented reality) and production (advanced robotics) I4.0 DTs can reduce the information processing costs associated with internationalisation.

Production robotics embedded with connected sensors and virtualisation tools (e.g., CAD 3D and virtual prototyping) reduces asset specificity and increases operational flexibility, which is essential for managing market diversity. Artificial Intelligence (AI)-powered robots increase operational flexibility by reducing production configuration costs and facilitating the organisation of different product lines (Li et al., 2021). Similarly, robots for inventory automation enhanced by AI applications can allow companies to manage variety (of products) and speed (in logistic flows) with increased control in a centralised

production unit, and additive manufacturing's reconfigurability supports operational flexibility (D'Aveni and Venkatesh, 2020).

Information I4.0 DTs lower transaction costs by adding information transparency and reducing information asymmetries. Real-time tracking and blockchain applications increase supply chain transparency and support trust (Cassetta et al., 2020; Schmidt and Wagner, 2019; Yamin and Sinkovics, 2006). Processes' digitalisation reduces transaction costs by enhancing information sharing and integration along supply chains (Denicolai et al., 2021), allowing firms to track user needs and reduce the distance between the firm and customers (Kollmann and Christofor, 2014). Furthermore, information I4.0 DTs can improve the operational embeddedness with customers, reducing the need for onsite proximity for customer assistance. Recent evidence suggests that information I4.0 DTs play a relevant role in shaping manufacturing firms' international production location decisions (Kinkel et al., 2023).

Information I4.0 DTs also facilitate the formalisation and replicability of organisational processes globally, supporting international growth. The digitalisation of operational knowledge allows firms to achieve "scalability without mass" and reduces the need for extensive bureaucratic structures (Brynjolfsson et al., 2008; Malone et al., 1993).

Moreover, the integration of production and information I4.0 DTs sustains the use of virtualisation logics that permit firms to balance market responsiveness, scalability and cross-border knowledge integration (Del Giudice et al., 2021). Virtualisation establishes a better link between the product engineering and manufacturing phases. Advanced robotics, informed by virtual prototyping, sensors, and AI, reduces general-purpose robotics's configuration costs and time to meet country-specific product requirements, reducing physical asset specificity. Virtualisation tools (e.g. digital twins) also facilitate complex, tacit knowledge transfer, reduce the time to market, and increase product quality. In addition, virtualisation enables companies to better apply advanced servitisation logic in their business model (Shleha et al., 2023). Firms might thus try to pursue market growth in the international market with a physically standardised product, leaving customisation to software and data analytics that can control product features (Porter and Heppelmann, 2015).

In conclusion, adopting and implementing information and production I4.0 DTs helps to reduce information asymmetry, limit bargaining frictions, constrain moral hazard, diminish asset specificity and the location-bound nature of firm-specific advantages due to the greater information availability and integration, increased control, reduced transaction costs and enhanced transferability of digital assets (Drori et al., 2024).

Based on the considerations discussed above, we can formulate the following hypothesis.

H1a. The adoption of production I4.0 DTs positively affects a firm's internationalisation performance.

H1b. The adoption of information I4.0 DTs positively affects a firm's internationalisation performance.

2.2. The moderating role of family management

Notwithstanding the remarkable developments in I4.0 DTs and the benefits we expect them to have for firms with an international reach, their actual impact on the internationalisation of firms is still debated due to the high level of managerial skills and technical governance needed to pursue their integration and capture the value of their recombinational power (Denicolai et al., 2021; Kinkel et al., 2023; Lanzolla et al., 2021).

I4.0 DTs generate new cybersecurity, strategic and operational risks for firms. A greater integration of I4.0 DTs into business operations is potentially a double-edged sword. While these technologies enable firms to optimise processes, enhance customer experiences, and unlock new markets, they also introduce some risks (Kessler et al., 2022; Parent and Reich, 2009). Cybersecurity risks are paramount, with firms becoming increasingly vulnerable to cyberattacks and data breaches as they digitalise operations. The complexity and sophistication of cyber threats have grown, leading to potential financial losses, operational disruptions, and reputational harm (Cavusoglu et al., 2004; Kessler et al., 2022).

Operational risks are also significant, as system downtimes and technical failures can disrupt business continuity and productivity. The increased technological dependency for critical operations means that any malfunction can have cascading effects throughout the organisation (Gatzert and Schmit, 2016; Sambamurthy et al., 2003; Tamvada et al., 2022).

Strategic risks arise when digital initiatives are misaligned with the overall business strategy and firms fail to appropriate the value of their investments (Banalieva and Dhanaraj, 2019; Kessler et al., 2022; Parent and Reich, 2009; Tallman and Li, 1996). Failed value capture can occur when firms underestimate the complementary organisational and system-level changes needed to make DTs effective, or when they become dependent on dominant technology suppliers due to dependency on proprietary platforms, control over data flows, or reliance on external expertise (Bharadwaj et al., 2013; Clegg et al., 1997). Moreover, I4.0 DTs have multiplied the possible strategic options firms must pursue, increasing both the level of competition and the complexity of business strategies to oversee (Jöhnk et al., 2022).

The prominence of cybersecurity, operational, and strategic risks varies with the type of I4.0 DTs adopted. Information I4.0 DTs typically entail cybersecurity risks due to their reliance on data exchange, cloud infrastructures, and external system integration, which broadens vulnerability (Cavusoglu et al., 2004; Kessler et al., 2022). They also pose strategic risks, as their value capture depends on effective integration: without the necessary cross-functional coordination, data governance, and strategic alignment, digital investments may underdeliver (Banalieva and Dhanaraj, 2019; Verhoef et al., 2021; Jöhnk et al., 2022). By contrast, production I4.0 DTs are mainly linked to operational risks, as failures can directly disrupt the continuity and performance of physical production processes (Gatzert and Schmit, 2016;Sambamurthy et al., 2003; D'Aveni and Venkatesh, 2020). Strategic risks may also arise when high sunk costs or supplier dependencies reduce firms' ability to adapt solutions across international markets (Bharadwaj et al., 2013; Lu and Ramamurthy, 2011).

The adverse role of family management. Since I4.0 DTs offer new opportunities and simultaneously pose new risks, the quality of corporate governance mechanisms in driving their adoption plays a salient role (Parent and Reich, 2009; Yeow et al., 2018). A crucial component of high-quality corporate governance is the TMT, whose role in guiding the firm's digitalisation is central (Garms and Engelen, 2019). Since the upper echelons theory (Finkelstein et al., 2009; Hambrick, 2007), we know that the characteristics and experiences of the TMT significantly influence organisational outcomes, especially in international business (Cuypers et al., 2022; D'Angelo et al., 2016) and peculiarly in the case of digitalisation (Bornhausen and Wulf, 2024). Following the underpinnings of such theory, non-family managers might be more proficient than family ones, at least and saliently, in terms of cognitive diversity, risk aversion, opportunity recognition and adaptation (Teece, 2007), and decision-making processes (Bornhausen and Wulf, 2024; Ceipek et al., 2021). These managerial traits can sustain firms in building dynamic capabilities out of the adoption of I4.0 DTs and give them agility and growth in international markets (Lee et al., 2015; Sambamurthy et al., 2003; Verhoef et al., 2021).

Non-family managers, especially those external to the firm, bring a broader range of experiences, industry knowledge, and innovative perspectives, which are crucial in digitalisation (Hillebrand et al., 2020). Diverse managerial teams are better equipped to integrate I4.0 DTs and allow for a more nuanced understanding of their application, especially in international contexts where adaptability and responsiveness are crucial (Garg and Eisenhardt, 2017; Kaplan and Vakili, 2015). In contrast, family managers often operate within a more homogeneous

cognitive framework shaped by the traditions and values of the family business, resulting in a conservative strategic approach, potentially limiting the firm's agility in sensing and seizing the opportunities brought by DTs (Lee et al., 2015; Teece, 2007; Verhoef et al., 2021; Yeow et al., 2018) and respond to global market demands (Banalieva and Eddleston, 2011; Chrisman et al., 2013; Duran et al., 2016; Matzler et al., 2015). Cognitive diversity is particularly relevant in mitigating strategic risks associated with information I4.0 DTs, which require interpretive capabilities to align data-driven tools with the firm's international strategy. Although operational risks from production I4.0 DTs are primarily technical, greater cognitive diversity within the TMT can enhance firms' ability to anticipate disruptions and develop more robust business continuity and disaster recovery plans (Kessler et al., 2022).

Also, upper echelons theory suggests that managers' risk appetites depend on their backgrounds and experiences. Managers not bound to the family tradition tend to be more open to taking calculated risks associated with digitalisation (Crossland et al., 2014). Their willingness to embrace innovation is crucial in a rapidly evolving digital landscape (Felin and Powell, 2016). On the other hand, family managers often exhibit greater risk aversion due to their vested interest in preserving the family legacy, which is usually a mandate of family ownership (Gómez-Mejía et al., 2019). This risk-averse behaviour can hinder the firm's ability to adopt disruptive technologies and enlarge the managerial team to specialists from outside. These circumstances lead to action or strategic inertia and the related missed opportunities (J. K. De Groote et al., 2021; Miller et al., 2011; Tripsas and Gavetti, 2017). This aversion is particularly consequential for information I4.0 DTs, where adoption often entails strategic uncertainty, cross-border data exposure, and cybersecurity vulnerabilities that require forward-looking, risk-tolerant leadership. Non-family managers may act more entrepreneurially, framing digitalisation as an opportunity rather than a threat, and mobilising the capabilities needed to pursue it effectively. In contrast, the operational risks linked to production I4.0 DTs generally materialise after implementation, reducing the relevance of top managers' risk appetite in mitigating their effects.

Family-managed firms typically limit the attraction of qualified and experienced human resources from outside to reinforce top and middle managerial positions to emphasise long-term stability and succession within the family (Camisón-Zornoza et al., 2020). Such emphasis on maintaining continuity and the limited attraction and retention of experienced resources from outside can limit the firm's ability to quickly adapt to the demands of digitalisation, particularly in international markets (Arregle et al., 2012). Conversely, non-family managers often focus more on achieving measurable short-to-medium-term performance gains through digital investments. Their drive for results can lead to more proactive and exploratory digital strategies (Cannella Jr et al., 2015; Ceipek et al., 2021). Limited external talent attraction constrain the firm's ability to build the organisational and technical capabilities needed to govern information I4.0 DTs, thereby amplifying both strategic and cybersecurity risks. For production I4.0 DTs, while some risks can be mitigated through vendor-led deployment, the growing complexity of interconnected systems, particularly those involving virtualisation or integration with design and engineering functions, makes talent attraction essential to ensure system reliability and cross-functional coordination across international sites.

Finally, family-managed firms often have centralised decision-making structures, leading to insular thinking and a reluctance to embrace external advice or innovative strategies (De Massis et al., 2015), which can slow the pace of digitalisation, as decisions are more likely to be influenced by a desire to maintain control and preserve the status quo (Bornhausen and Wulf, 2024; Gómez-Mejía et al., 2007; Zahra et al., 2004). In contrast, non-family managers typically operate within more formalised and transparent governance frameworks that emphasise accountability and inclusion of diverse viewpoints (Hoskisson et al., 2017). For example, the CEO's digital orientation and board members' digital expertise might positively influence the breadth of expected strategic options a firm can pursue (Filatotchev et al., 2023). Formalised and inclusive governance is essential for managing the strategic risks associated with both information (scarce value capture due to lack of integration) and production I4.0 DTs (high sunk costs and supplier dependency). In both cases, decentralised and inclusive decision-making processes enhance the firm's ability to respond to contextual variability and support better integration and adaptability.

Therefore, non-family management appears critical to enhancing corporate governance quality and effectively managing the risks and opportunities associated with both information and production I4.0 DTs. This type of argument echoes the studies showing that I4.0 DTs can have the paradoxical effect of increasing rigidity in firms with less advanced managerial practices (Guo et al., 2023; Lu and Ramamurthy, 2011). Consequently, we formulate our second set of hypotheses.

H2a. Family management negatively moderates the effect of adopting production I4.0 DTs on a firm's internationalisation performance.

H2b. Family management negatively moderates the effect of adopting information I4.0 DTs on a firm's internationalisation performance.

3. Methods

3.1. Data and variable definitions

The empirical analysis is based on data from the last three RIL waves conducted by INAPP in 2010, 2015, and 2018 on a representative sample of partnerships and limited liability firms. From the longitudinal component of the RIL dataset, we keep those firms with at least five employees and no missing information for crucial variables, ending with a longitudinal sample of about 3000 firms over the period under study.

I4.0 DTs adoption. The 2018 wave of the RIL-INAPP survey includes a question specifically designed to collect information on I4.0 DTs adoption in 2015–2017, which sounds as follows: "In the period 2015–2017, did the firm invest in new technologies?". The respondents can choose from the following answers: IoT, robotics, big data analytics, and augmented reality (see the Appendix for more details). Although multiple answers are allowed, we adopt a dichotomous measure of I4.0 investment and code a variable equal to 1 if a firm invested in at least one specific technology and 0 otherwise (Cirillo et al., 2023).

Further, we disentangle the nature of I4.0 DTs by defining two dummy measures of I4.0 DTs investments: the first identifies the subset of information I4.0 DTs (IoT, big data analytics and augmented reality), and the second one measures the adoption of production I4.0 DTs (robotics) (Frank et al., 2019).

International performance. Concerning our outcome variable, the RIL-INAPP questionnaire tracks various dimensions of internationalisation, such as presence abroad, share of sales from foreign markets, and FDIs. Taking advantage of the wealth of information the survey provides, we opt for a very granular measure of internationalisation and compute the sales from selling products and services on foreign markets per employee, which assesses international performance. In the Appendix, we show results with an alternative definition, a dichotomous indicator equal to one if the firm sells products or services on foreign markets and zero otherwise.

Family management. Regarding the moderation effect exerted by family management, the RIL-INAPP questionnaire allows us to define a dummy that captures family management. Each firm was asked whether the person who manages the enterprise is a family member who owns or controls the company. Hence, we distinguish businesses run by managers recruited from the external market from those with family managers.

Control variables. One advantage of the RIL-INAPP survey is the richness of information it collects, which permits control for an ample range of confounding factors. We extract information about the workforce and TMT characteristics regarding human capital and professional

categories. Moreover, the data contains extensive firm-level controls, such as information about industrial relations, the number of employees and innovative outcomes. Table A5 in the Appendix provides a detailed description of each variable.

3.2. Econometric strategy

To assess the quantitative effect of various I4.0 DTs on international performance, we estimate the following equation:

$$Y_{i,t} = \alpha_1 DT_i + \alpha_2(DT_i \cdot 2018) + \alpha_3(DT_i \cdot 2014) + \beta_1 MWF_{i,t} + \beta_2 FM_{i,t} + \vartheta_1(s_{i,t}{}^{*}r_{i,t}) + \vartheta_2(s_{i,t}{}^{*}d_{i,t}) + \mu_i + \lambda_t + \varepsilon_{i,t} \quad [1]$$

Where $Y_{i,t}$ indicates the (log of) sales per employee from selling products and services on foreign markets for each firm i in years $t = 2010, 2015, 2018$. Our key explanatory variable, DT_i, is a dummy capturing the adoption of I4.0 DTs. In separate regressions, we test the effect of the dummy being equal to 1 whether the firm invested in information, production or at least one I4.0 DT over 2015–2017 and 0 otherwise. Then, the treatment group comprises firms declaring to have invested in new technologies over 2015–2017 (DT_i=1), while the control group comprises firms that did not invest (DT_i=0).

The time variable 2018– the year of the survey wave collecting information about the 2015–2017 investments – is an indicator for the post-treatment period, and 2014 remarks the pre-treatment period. The interaction term DT_i·2018 identifies the Diff-in-Diffs effect of I4.0 DTs adoption while DT_i·2014 allows us to check the Common Trends Assumption (CTA) with reference to the initial omitted year, 2010. The CTA implies that we should observe parallel trends in the outcome variable for treated and control groups without treatment. If CTA holds, the Diff-in-Diffs estimator removes any time-varying effect influencing the treatment and control groups.

The vector $MWF_{i,t}$ includes a comprehensive set of control variables capturing organisational and economic firms' characteristics, further shielding our estimates from omitted variable bias. We single out family management ($FM_{i,t}$ in the equation) from the control variables for transparency, even though we are not interested in its direct effect on the outcome variable.

Concerning the time-invariant and unobserved forces that may influence our relation of interest, we implement a fixed effects (FE) approach. The parameter μ_i captures firms' time-invariant unobserved heterogeneity, λ_t are year dummies, the interaction terms $(s_{i,t}{}^{*}r_{i,t})$ and $(s_{i,t}{}^{*}d_{i,t})$ formalise 2-digit sector-by-firms' size and 2-digit sector-by-regions FE, respectively. These terms account for the heterogeneous patterns across sector-specific technologies that vary between geographical regions and firm size. Finally, ε, is the idiosyncratic error term.

Moreover, we combine the Diff-in-Diffs FE model with Propensity Score Matching (PSM). PSM relies on the idea of running regressions on the restricted samples of treated and control firms with similar observable characteristics. As the Diff-in-Diffs FE method is designed to account for time-invariant unobservable factors influencing outcomes between treated and control firms, by combining PSM and Diff-in-Diffs FE approaches, we implement a hybrid model that may perform better than standard ones alone (Cerulli, 2015; Heckman et al., 1998).

To adjust for observable differences between treated and untreated units, the matching procedure takes advantage of the wide set of explanatory variables introduced in the previous section and detailed in Appendix Table A5. Indeed, we include variables on management and corporate governance, workforce composition and other firm-level characteristics such as age, size, sector and innovation. The richness of the information collected by the RIL survey is expected to create a good balance between the characteristics of treatment and control firms.

Note that this strategy is suitable for dealing with the "first adopters" issue, even though we have no explicit information about using I4.0 DTs from 2015 to 2017. Indeed, I4.0 DTs diffusion in Italy was scarce before 2015, whereas it peaked in the following period because of the introduction of the Italian National Plan Industry 4.0. Further, the PSM balances the treatment and control groups on a comprehensive variety of firm features that strongly correlate with the probability of investing in technological advancements. Hence, even though we do not observe pre-treatment adoption, we can figure it as a latent variable that, thanks to the PSM, is evenly distributed across our groups. In the Appendix, we directly tackle the "first adopters" issue by exploiting information on past investments in ICTs (Bratta et al., 2022; Romano, 2018), considered an antecedent and enabler of subsequent digital investments. Operatively, we run the exercise on the subsample of firms that did not invest in information/hardware devices in the initial period of the analysis.

A simple OLS estimation of the correlation between I4.0 DTs investments and international performance is likely vulnerable to biases. Indeed, one may argue that competitive firms in global markets might be more resourceful and, thus, more capable of investing in new technologies. They might also have access to broader human and financial capital markets, enabling them to pursue I4.0 DTs development effectively (Cirillo et al., 2023; Gal et al., 2019). We are confident that our quantitative framework is well-suited for accounting for the potential reverse causality issues. The Diff-in-Diffs FE model compares "treated" firms that invested in I4.0 DTs over 2015–2017 with the "control" firms that did not. The timing of the Italian National Plan Industry 4.0 helps our identification: the policy introduced (mainly after 2016) a set of horizontal fiscal incentives to lower financial constraints on technological investments and sustain the digital transition. In the short run, such an external shock may be considered a sort of exogenous variation in the treatment concerning international performance.

Finally, the econometric analysis tests whether family management matters as a "moderating" factor in shaping the effect of digitalisation on the outcome variables. Thus, we follow Wooldridge (2010)and formalise a triple Diff-in-Diffs FE model of equation (1):

$$Y_{i,t} = \alpha_1 DT_i + \alpha_2(DT_i \cdot 2018) + \alpha_3(DT_i \cdot 2014) + \alpha_4(DT_i \cdot 2018 \cdot FM_{i,t}) + \alpha_5(DT_i \cdot 2014 \cdot FM_{i,t}) + \alpha_6(DT_i\, FM_{i,t}) + \beta_1 MWF_{i,t} + \vartheta_1(s_{i,t}{}^{*}r_{i,t}) + \vartheta_2(s_{i,t}{}^{*}d_{i,t}) + \mu_i + \lambda_t + \varepsilon_{i,t} \quad [2]$$

Where the coefficient of the triple interaction ($DT_i \bullet 2018 \bullet FM_{i,t}$) as compared to $(DT_i \cdot 2014 \cdot FM_{i,t})$ is expected to measure the effect of I4.0 DTs "filtered" or "corrected" for the presence of family management. The model is saturated with the first-level interactions whose impacts are captured by coefficients α_2, α_3 and α_6 while the other firm-level controls and parameters are the same as before.

Note that a single Common Trend Assumption test is required for the Triple Diff-in Diffs specification reported in equation [2], and then we test the statistical significance of the coefficient associated with the triple interaction DT_i·2014·$FM_{i,t}$ (Olden and Møen, 2022). In addition, coefficient estimates α_2 and α_3 allow us to verify whether the overall result about I4.0 DTs' "direct" effect on international performance is also confirmed. Such a test enables us to thoroughly control potential confounding factors that hinder the identification and magnitudes of the primary relationship under study.

3.3. Qualitative inquiry

Despite the appropriateness of our empirical approach to estimate the linkage between I4.0 DT adoption and international performance, and the moderating effect of TMT provenance, the presented quantitative evidence has limited explanatory power (Dabić et al., 2020). While the quantitative analysis allows us to establish generalisable effects and test for systematic variation across firms, it cannot account for organisational frictions and managerial challenges that shape digital implementation in context. Hence, we adopt a complementary qualitative approach (Yin, 1994), aimed not at corroborating the statistical results but at deepening them. A qualitative analysis through case studies

expands our understanding of how I4.0 DTs are enacted within firms, what hurdles emerge during internationalisation, and how managerial capabilities influence the translation of digital investments into international performance. In doing so, it enriches the analysis by revealing mechanisms and contingencies that remain invisible in the large-scale data.

Our qualitative inquiry was conducted in two stages. In the first stage, a larger research team conducted 26 in-depth explorative case studies. Firms were selected to increase the variety of sectors and size among medium-sized and large enterprises. The analysis excluded information services such as financial services, education, software and consulting due to their information-intensive structure that influences firms' business and digital strategies (Pesce and Neirotti, 2023), and agriculture was also excluded due to the specificities of its operations. These cases focused on I4.0 DTs adoption, its managerial and strategic antecedents and its outcome. The results of these case studies have been illustrated by Mazali et al. (2023).

Out of the 26 cases, five were selected and analysed more in-depth since they offered a "revealing context" in which the effect of TMT characteristics on the linkage between digitalisation and international performance could be "transparently observed" (Yin, 1994, p. 40). These five internationalised firms are located between Piedmont (Northern Italy) and Apulia (Southern Italy), and they share a marked digital orientation of their CEOs (Hervé et al., 2020).

A more focused interview on the linkage between I4.0 DTs adoption and internationalisation occurred between the end of 2022 and 2023. A second round of brief interviews was run at the beginning of 2025 to comply with requests that emerged during the revision process. We opted for a semi-structured interview format, allowing knowledge to emerge bottom-up and recognising specific patterns among recorded evidence afterwards (Adams, 2015; Langley, 1999). The questionnaire had three main sections. The first one investigated which I4.0 DT the company has invested in. The second probed the company's international market presence. Finally, the third examined how these technologies have influenced the company's ability to enhance international competitiveness. The second round of interviews, instead, focused on the role of the management to mitigate the risks brought by digitalisation.

To avoid threats to the validity of the case studies, we set up a protocol to run the interviews (Yin, 2017). Each interview with the CEO lasted one to 2 h and involved two researchers. We integrated information from various sources, such as sustainability reports, corporate websites and material from the first stage of the inquiry. After each interview, we transcribed and examined the recordings and iteratively confronted the interviews' results with the existing theoretical literature on the internationalisation-digitalisation nexus (Battaglia et al., 2021; Burawoy, 1991).

4. Results

4.1. Descriptive statistics

Herein, we briefly describe our sample along the dimensions relevant to our study, whose descriptive statistics are reported in Table 1. On average, 29 % of firms operate on international markets, and 9 % is the percentage of sales obtained from selling products or services internationally (2.6 is the average log of total sales per employee). 14 % of firms invested in at least one I4.0 DT between 2015 and 2017, while 11 % and 5 % adopted information I4.0 DTs and robotics, respectively, indicating that Italian businesses are still poorly digitalised. About 2 % are multinationals, and over 90 % of companies employ less than 50 workers, confirming the renowned small dimensionality of the Italian firm's population.

It is worth discussing the main differences between firms that invest in I4.0 DTs and those that do not. The descriptive statistics are reported in Table 2. In support of our first two hypotheses, digitised firms are more internationally performant in both the intensive and extensive margins than firms that have not invested. Similarly, the first group of firms is characterised by a relatively higher incidence of highly educated managers, a higher share of workers with a college degree, and a stronger innovative propensity in productive processes and products.

Table 1
Descriptive statistics on the whole sample.

	N of Obs	Mean	Std dev	Min	Max
	Foreign markets and I4.0 DTs				
Foreign markets (0/1)	8562	0.289	0.453	0	1
% Sales from foreign markets	8562	9.009	2.136	0	100
Log of sales from foreign mkt pc	8562	2.941	4.719	0	13.090
At least one I4.0 DT	8562	0.139	0.346	0	1
Information I4.0 DTs	8562	0.110	0.312	0	1
Robotics	8562	0.051	0.221	0	1
TMT characteristics					
Tertiary education	8562	0.231	0.421	0	1
Upper secondary education	8562	0.543	0.498	0	1
Female	8562	0.142	0.349	0	1
Family management	8562	0.905	0.294	0	1
Workforce composition					
Share of tertiary education	8562	0.097	0.187	0	1
Share of upper secondary education	8562	0.483	0.305	0	1
Share of lower secondary education	8562	0.420	0.330	0	1
Share of aged workers	8534	0.236	0.211	0	1
Share of middle-aged	8534	0.477	0.229	0	1
Share of executives	8562	0.038	0.091	0	1
Share of white collars	8562	0.380	0.313	0	1
Share of blue collars	8562	0.582	0.330	0	1
Firms characteristics					
Multinational ownership	8562	0.018	0.134	0	1
Employers' association	8562	0.612	0.487	0	1
Firms age (in years)	8562	26.927	14.828	0	338
IRAP tax cut	8562	0.024	0.154	0	1
Product innovation	8562	0.381	0.486	0	1
Process innovation	8562	0.325	0.468	0	1
Log of number of employees	8562	2.501	0.834	1.6	9.2

Source: authors' calculations on RIL longitudinal sample. Note: pooled 2010-2015-2018 data. Sampling weight applied.

Concerning our second two hypotheses, Table A1 in the Appendix completes the picture and reports the average differences between firms run by family managers and those not. Firms with family management are slightly less present in international markets (28.7 % vs 31 %), sell fewer products and services abroad as a share of total sales (8.6 % vs 12.5 %), and show a weaker propensity to adopt I4.0 DTs (13.5 % vs 18 %). Such a divide in digital propensity suffered by firms with family management is entirely due to information I4.0 DTs (10 % vs 15 %), while investments in robotics are higher for firms run by family managers. These features pair with the low incidence of family managers with tertiary education (20 % against the 45 % in firms without family management) and with the lower human capital endowment of the workforce in the firm they run as it emerges by observing both the share of workers with tertiary education (8.7 % vs 19.4 %) and the share of executives (3.3 % vs 8.6 %). Moreover, we observe that firms with family management are smaller and experienced less frequent product and process innovations in the recent (three-year) period.

4.2. The effect of I4.0 DTs adoption on international performance

Table 3 reports Diff-in-Diffs FE estimates of equation [1] on the matched sample obtained by running PSM. In particular, treated and control firms are identified based on their likelihood of investing in I4.0 DTs. To assess the matching quality, we evaluated the differences between the mean values of a subset of the variables (sectoral dummies are not reported to save space) that are used to match the treatment and

Table 2
Descriptive statistics by I4.0 DTs investments.

	Investing		Not investing	
	Mean	Std dev	Mean	Std dev
	Foreign markets and I4.0 DTs			
Foreign markets (0/1)	0.434	0.496	0.265	0.442
% Sales from foreign markets	13.783	24.594	8.236	20.696
Log of sales from foreign mkt pc	4.422	5.183	2.702	4.595
Information I4.0 DTs	0.786	0.410	0	0
Robotics	0.368	0.482	0	0
TMT characteristics				
Tertiary education	0.277	0.448	0.223	0.416
Upper secondary education	0.541	0.498	0.543	0.498
Female	0.129	0.336	0.144	0.351
Family management	0.878	0.327	0.909	0.288
Workforce composition				
Share of tertiary education	0.117	0.184	0.094	0.187
Share of upper secondary education	0.482	0.282	0.483	0.309
Share of lower secondary education	0.401	0.313	0.422	0.333
Share of aged workers	0.217	0.192	0.239	0.214
Share of middle-aged	0.477	0.205	0.477	0.233
Share of executives	0.034	0.076	0.039	0.093
Share of white collars	0.412	0.312	0.374	0.313
Share of blue collars	0.553	0.322	0.587	0.331
Firms characteristics				
Multinational ownership	0.017	0.129	0.018	0.135
Employers' association	0.655	0.476	0.605	0.489
Firms age (in years)	27.779	14.362	26.789	14.898
IRAP tax cut	0.042	0.200	0.021	0.145
Product innovation	0.596	0.491	0.346	0.476
Process innovation	0.577	0.494	0.284	0.451
Log of number of employees	2.930	1.055	2.432	0.770
N of obs	1817		6745	

Note: pooled 2010-2015-2018 data. Sampling weight applied.
Source: authors' calculations on RIL longitudinal sample.

Table 3
Estimates of Diff-in-Diffs with FE. Matched sample. Dependent variable: (log of) sales from international markets per capita.

	[1]	[2]	[3]
DT*year2018	0.723***		
	[0.256]		
DT*year2014	0.395		
	[0.253]		
Information DT*year2018		0.467**	
		[0.222]	
Information DT*year2014		0.254	
		[0.223]	
Robotics*year2018			0.330
			[0.236]
Robotics*year2014			0.242
			[0.232]
Year2018	−0.281	−0.015	0.168
	[0.228]	[0.180]	[0.151]
Year2014	−0.130	0.014	0.050
	[0.221]	[0.172]	[0.140]
FM	−0.086	−0.105	−0.106
	[0.281]	[0.281	[0.281]
Constant	5.225***	5.171***	5.129***
	[0.512]	[0.512]	[0.512]
Other controls	Yes	Yes	Yes
N of Obs	3041	3041	3041
N of Firms	1064	1064	1064
R2	0.868	0.867	0.867

Note: All regressions include interactions between 2-digit sectors and NUTS2 regions and firm size (in classes) FE. Robust standard errors in parentheses are clustered at the firm level. Statistical significance: *** at 1 %, ** at 5 %, * at 1 %.
Source: author's elaborations on RIL-ORBIS data.

control groups. Overall, the figures confirm that the treated and control firms, though initially different, appear similar and balanced after the match (see Table A3 in the Appendix).

We observe that the I4.0 DTs adoption leads to a rise in the log of sales from foreign markets by 72 %, with an average increase of 24 % annually (column 1). Estimates associated with information I4.0 DTs are lower in magnitude (+46 %) and equal to a rise of 18 % yearly (column 2). In both cases, the coefficient estimates of the interaction terms between I4.0 DTs and the pre-treatment year 2014 support the validity of the CTA and, consequently, the parallel trends between treated and control groups.

Conversely, column 3 reveals that robotics exerts no significant impact on foreign market performance. Consequently, we conclude that only H1b is supported and H1a is not. Moreover, we signal the not-statistically significant coefficient capturing the direct effect of family management.

4.3. The moderating role of family management

In this section, we present the triple Diff-in-Diffs FE results aimed at verifying the role of family management in shaping the relationship under study. This issue is considered in Table 4.

Namely, estimates in column 1 show that firms with family management adopting at least one I4.0 DT experienced a reduction of the sales per capita by 31 % yearly compared to firms run by managers external to the family (estimates of DT*year2018*FM). Note that the coefficient associated with DT*year2014*FM is not statistically different from zero, implying that CTA holds. Also, column 1 confirms a positive direct effect of I4.0 DTs, the magnitude of which increases to 35 % yearly (see DTs*year2018) once the indirect negative role of family management is accounted for.

Analogously, column 2 indicates that adopting information I4.0 DTs

Table 4
Triple Diff-in-Diffs with FE. Dependent variable: (log of) sales from international markets per capita.

	[1]	[2]	[3]
DT*year2018	1.136***		
	[0.156]		
DT*year2014	0.086		
	[0.216]		
DT*year2018*FM	−0.932**		
	[0.283]		
DT*year2014*FM	0.066		
	[0.356]		
Information DT*year2018		1.102***	
		[0.377]	
Information DT*year2014		0.065	
		[0.384]	
Information DT*year2018*FM		−0.950**	
		[0.438]	
Information DT*year2014*FM		0.095	
		[0.441]	
Robotics*year2018			0.676
			[0.310]
Robotics*year2014			0.339
			[0.231]
Robotics*year2018*FM			−0.383
			[0.302]
Robotics*year2014*FM			−0.130
			[0.253]
Year2018	−0.383	−0.336	−0.14
	[0.178]	[0.215]	[0.129]
Year2014	−0.015	−0.011	−0.03
	[0.139]	[0.202]	[0.146]
Constant	3.920***	3.901***	3.891***
	[0.122]	[0.334]	[0.123]
Other controls	Yes	Yes	Yes
Obs	8562	8562	8562
R2	0.798	0.801	0.798

Note: All regressions include interactions between 2-digit sectors and NUTS2 regions and firm size (in classes) FE. Robust standard errors in parentheses are clustered at the firm level. Statistical significance: *** at 1 %, ** at 5 %, * at 1 %.
Source: author's elaborations on RIL-ORBIS data.

in firms with family management leads to a yearly decrease of sales per capita by 31,5 % and that the parallel trend assumption holds. Again, information I4.0 DTs direct effect increases to 34 %. Conversely, column 3 shows that estimated coefficients for interaction terms are statistically not different from zero, suggesting that robotics influence international performance neither directly nor indirectly throughout the presence of family management. Hence, coherently with the results on H1a and b, we find support for H2b, but H2a is not supported.

4.4. Qualitative results

Herein, we briefly describe each case and focus on three dimensions: I4.0 DTs adoption, internationalisation, and management's role.

4.4.1. Firm A: virtualisation in luxury fashion engineering

I4.0 DTs adoption. Founded in 2000 by two experienced pattern makers, Firm A initially specialised in men's outerwear but has since evolved into a diversified luxury fashion engineering company with around 800 employees. It provides a full spectrum of services, including design, engineering, prototyping, and production, catering to some of the world's top luxury fashion brands, including those clustered in Milan, London, Paris, and New York.

In 2012, a transformative shift occurred when a non-family CEO with a strong background in another luxury sector – yacht shipbuilding – and an MBA was appointed. The new CEO's immediate goal was to formalise previously informal processes, bringing structure and efficiency to a company that thrived on a craftsmanship-driven culture.

> «We had to organise ourselves: this company in 2011 had no contracts with suppliers or customers, there was no process, no organisation, no organisational chart. It was born and grew well, in a healthy way, but with a culture linked to the world of tailoring, not to that of a large company»

Under his leadership, Firm A embarked on a technological transformation. It became one of the early adopters of virtualisation technologies, including 3D CAD systems, allowing for virtual garment prototyping. This digitalisation meant clients could now review and provide feedback on designs remotely, reducing the need for physical prototypes and cutting shipping times and costs. It also enabled the firm to respond more quickly to market trends, increasing its ability to deliver new collections in a fast-paced luxury market.

Additionally, the company embraced blockchain technology to improve supply chain transparency, a critical move given the increasing scrutiny on sustainability in the fashion industry. Firm A further solidified its commitment to sustainability by adopting laser bonding technology to enhance environmental sustainability.

> «We have introduced laser bonding technologies for fabrics made from recycled ocean plastics. We hardly sew anything anymore»

Internationalisation. Firm A's international strategy has been heavily driven by its technological innovation. Its international exposure is massive: serving the global leaders of the luxury sector, 95 % of its production goes abroad, where the leading fashion companies reside. Firm A built its competitive edge through technology. The adoption of virtual prototyping allowed the company to accelerate time-to-market, an essential factor in the luxury industry where product cycles are increasingly rapid. Blockchain and laser technology further bolstered the firm's reputation as a sustainable, tech-savvy supplier, enhancing its appeal to high-end fashion brands with a focus on environmental impact.

> «As an emerging company, gaining recognition from top luxury brands hinges on demonstrating mastery of cutting-edge digital technologies. Once you have that initial foothold, it's crucial to showcase your unique engineering expertise. However, for us as an Italian firm with a proven track record working with iconic names like Armani and Valentino, proving our excellence is second nature»

Management's role. The shift from a family-led management structure to a more professionalised one, guided by a non-family CEO with a digital orientation, was a turning point for Firm A. The new CEO fostered two acquisitions and introduced external managers in critical roles, such as Operations Director and ICT Manager, formalising the firm's decision-making processes and creating a structure that could scale internationally. The focus on digitalisation and the managerial shift allowed Firm A to meet its international clients' demands better, enhancing its operational efficiency and global reputation.

> «He managed to structure the managerial process, meaning he really codified something that was very confusing and difficult»

Although successful, transitioning from an analogic or digital 2D to a digital 3D design was daunting, and the possibility of upskilling the workforce was limited, implying difficulty in coordinating incumbent and novel digital-native workers.

> «The digitalisation in two dimensions was quite simple; conceptually, we were talking about the same job, simply done with a different support. The three-dimensional digitalisation has been extremely complicated and could not be done with the same people; a 2D modeller remains a 2D modeller»

The CEO's openness and readiness to experiment and adopt novel technologies and organisational solutions had been crucial to overcoming such a hurdle that was more a "cultural theme" than a technological one.

In conclusion, the combination of virtual prototyping, blockchain technology, and a professionalised management team led by a non-family CEO enabled Firm A to thrive in the competitive global luxury fashion market. By integrating these technologies, the firm was able to reduce costs, improve sustainability, and increase the speed of its product development cycles, all of which contributed to its international success.

4.4.2. Firm B: complex analytics and servitisation in automated warehousing

I4.0 DTs adoption. Firm B, founded in 1957 as a furniture manufacturer, transitioned in the 1980s to producing automated warehouses for the manufacturing and retail sectors. With about 120 employees, the company has become a leader in its field, investing approximately 9 % of its revenue in R&D to stay at the forefront of technological innovation.

In 2019, Firm B implemented an Enterprise Resource Planning (ERP) system and a Manufacturing Execution System (MES) to provide more granular control over production costs and time. Additionally, augmented reality tools were introduced to support training for operators and reduce the time expatriates spend installing or maintaining automated warehouses at customer sites abroad.

> «Augmented reality tools reduce the time expatriates spent at customer sites, improving both our service and operational efficiency»

A second technological trajectory entails deploying the IoT and AI in a new generation of smart and connected automated warehouses. Connectivity has allowed for ensuring remote control of the asset, more prompt assistance and maintenance to international customers, and the use of prescriptive or predictive logic to support inventory optimisation. The firm now explores such capabilities in emerging markets, like inventory control in quick-commerce warehouses. This technological and business model innovation trajectory has forced the company to invest in new procedures or embrace new protocols for cyber security and customer data protection in the integration between customers and the company, a critical success factor for clients like Tiffany (retail of jewellery) or the Mexican State Mint.

Internationalisation. Firm B began its internationalisation efforts in the early 2000s, and, today, 35 % of its revenues come from exports. Indeed, Firm B's primary market is still domestic, and the CEO attributes such relatively low international exposure partly to the lack of adequate commercial capabilities and partly to the characteristics of the business model.

> «Our business model requires partners in the territory not only with commercial skills but also technical skills for installation, assembly, and maintenance. This requirement risks reducing partnership potential: not all territories possess adequate skills. We are not champions of internationalisation, which also depends on inadequate commercial skills»

In line with the need to improve international growth, in July 2023, the company underwent capitalisation and welcomed a private equity fund into its ownership structure, where the family now owns a minority share of the equity.

> «This operation was motivated by two main factors: generational transition and the need to compete on an international scale. We evaluated several options and ultimately chose to collaborate with a fund to accelerate growth and strengthen our presence in global markets.
>
> [..]We are evaluating strategic acquisitions to grow further, particularly in the United States. The first ongoing operation concerns a distribution company, which will allow us to strengthen our presence in the American market without the immediate need for production localisation»

Management's role. Managers face new developmental challenges when the company starts pursuing a digital strategy based on smart connected products and systems and thus need to build new digital processes related to clients' data storage and management and more intimacy with the customers. The development of these digital processes and the necessity to ensure data security and compliance with local regulations have amplified the capital intensity of the firm's operational model and, even before capitalisation, the demand for specialised roles in each department and for qualified managerial roles.

> «We are talking about a company with around 120 employees, over 65 of whom are office staff, and more than 50 are university graduates. The head of finance and management control, as well as all administrative staff, hold a degree. Essentially, apart from my four brothers and the two other board members, all the company's top management comes from outside the family. Over time, I have brought in high-level external professionals. Even my brother, who was in charge of operations on the board, gradually transitioned to focus on specific areas: a few years ago, I replaced him with an engineer from a major company, who has since led operations reorganisation, digitalisation, and automation. The same applies to the finance and administration department, which, for the past 15 years, has been entirely managed by a team of highly skilled professionals, replacing my accountant brother»

Indeed, the managerial structure of Firm B was evaluated positively by the new property, which intervened to complete the transition towards an experienced external TMT and strengthen international competencies.

> «The fund analysed our managerial structure and identified some areas for improvement, particularly in the commercial sector. As a result, we hired a new foreign sales manager to strengthen our international distribution network. Subsequently, this figure took on responsibility for the entire commercial sector, introducing new strategies and operational tools that have already begun to deliver concrete results»

In conclusion, Firm B's adoption of complex analytics and IoT technologies has been central to its international growth. By leveraging these tools to enhance its servitisation offering, the company was able to provide more tailored solutions to its global customers. Parallel to technological developments, Firm B progressively restructured and enhanced its managerial structure, culminating in the recent capitalisation.

4.4.3. Firm C: operational flexibility in automotive manufacturing

I4.0 DTs adoption. Firm C, founded in 1891, is a tier-1 and tier-2 supplier in the automotive sector, specialising in hot moulding and mechanical machining for commercial and heavy-duty vehicles. The company, with approximately 130 employees, has adopted advanced manufacturing technologies to improve its operational flexibility and meet the increasingly complex demands of its clients. By introducing a MES, Firm C could comply with the highest international manufacturing standards and satisfy traceability requests of multinational clients.

> «In the automotive industry, there are both explicit and implicit rules that require strict adherence to protect ourselves, as it's a highly demanding and competitive sector. Every component we produce must be traceable—knowing exactly where, when, and how it was made is crucial, especially given the large volumes we handle. […] We developed a traceability system that integrates production lines with iPads at the machine level, allowing real-time management of process parameters»

The MES provided Firm C with real-time visibility into its production processes, allowing for more efficient use of resources and ensuring that quality standards and more profound cost control were consistently met. This digital backbone enabled the company to offer vertically integrated production solutions to its international clients.

> «Before embracing Industry 4.0, we didn't have the type of production we manage today. As the value we provide increased, we had to make significant investments in operational management to safeguard our operations. These digital investments, particularly in our MES, have been essential in supporting the technological upgrades. Without such systems, investing in advanced technology alone would have been a reckless decision»

Internationalisation. Firm C has steadily increased its exports-to-sales ratio, reaching 65 % in 2023. Integrating MES and advanced industrial robots allowed Firm C to consolidate distinct production stages previously spread across multiple locations and suppliers into a single facility. The company's ability to integrate multiple production stages into a single facility made it an attractive partner for international clients looking for cost-effective, high-quality solutions.

> «We invested heavily in the brake, focusing not on producing something others don't have, but on attracting customers by offering it as a finished product—whereas it typically involves multiple suppliers. Technologically, we have invested in molding and machining, as well as laser hardening and other technologies that were new to us. We offer clients the ability to consolidate five or six production phases, usually spread across Europe, into a single supplier. We have integrated the entire production process»

I4.0 DTs such as MES and traceability systems supported Firm C's growth in international markets and proved fundamental in facing the increasing complexity of international norms and standards.

> «From a relational and organisational perspective, a company like ours—despite its family-business size—must respond to top-tier clients and global players with the same standards as a multinational in our field. This includes ESG compliance, emissions tracking, and other structured processes that have become essential market requirements. Today, responding to a tender is no longer just about feasibility, process, and price. These aspects are now secondary to where and how you produce, how much energy you consume, and

whether it's from green sources. Even the simplest request for proposal includes extensive questionnaires, which have evolved from self-assessments into near-parallel certifications»

Another difficulty arises from quality management with distant clients. Nowadays, anomaly reporting is fully automated: because no human mediation takes place, the margin for mistakes is nihil. Since contracts impose very short-term responses from suppliers (within 8 h), Firm C must act quickly to prevent production line disruptions when a foreign customer's automatic machine reports an anomaly. Such a condition led Firm C to create and coordinate a web of specialised suppliers who directly handle the selection and management of defective products in the target markets.

Management's role. The aforementioned digitalisation of production processes was not without obstacles. The workforce's difficulty adapting to change exposes Firm C to potential system-level failures.

«The main challenge—and we're still not past it—is cultural. Despite training, we continue to struggle. The approach is: 'If this doesn't work, I stop.' Initially, [the app] was just a login and piece-counting system. Today, it handles everything: control plans, drawings, and machine-side inspection instructions. And that's where the difficulties begin. If the system doesn't start, if an iPad won't connect, production stalls. If the servers fail to generate shipping documents or record production, everything stops. We've digitalised the production line to the point where every workstation must interface with the system. If something doesn't work—or if the operator can't manage it—everything comes to a halt»

The difficulties related to digitalisation and international exposure required an adequate response at managerial levels. One key hire was a quality manager with extensive experience at a major client, who helped deploy the lean corporate program widely adopted by the firm's main international customer. At the middle level, new roles in security, sustainability, data analytics, and product and process engineering emerged and quickly became structural. Of the company's new hires, 50 % were operative, and 50 % related to management and organisation, Firm C says. These managerial changes were essential in improving Firm C's overall equipment effectiveness (OEE), which increased from 66 % to 75 % over three years.

«Meeting [the quality manager] was a strategic opportunity to "change" and renew the organisation, and quality management of processes. Equipping ourselves with a method of continuous improvement was essential to "be ready" to face emerging challenges. [the quality manager], thanks to his experience and knowledge of the continuous improvement method that our main client had already implemented, was the right person to help "grow" our company»

In conclusion, Firm C's investment in I4.0 DTs, such as MES and traceability systems, significantly improved its operational flexibility and offered more comprehensive solutions to its international clients. The introduction of an external top manager and upgrading the managerial structure was critical in driving these improvements, ensuring the company's digital transformation aligned with its global growth strategy.

4.4.4. Firm D: digital traceability in wine and spirits Labeling

I4.0 DTs adoption. Founded in 1966, Firm D is a family-owned company specialising in printing high-value-added labels for high-end wines, spirits, and cosmetics. The company has grown into a global operation with production plants in six countries: Italy, France, Scotland, the USA, Mexico, and India. Employing around 1000 people, Firm D has positioned itself as a leader in the market by focusing on customisation and co-design with its clients.

Labels are critical in branding wines and spirits, serving as the "zero moment of truth" for customers. In recent years, Firm D has adopted digital traceability and advanced digital printing technologies to meet the demands of international clients in the spirits market for quality, innovation, customisation and low production volumes. By integrating IoT solutions into its digital offset printing machines, Firm D enhanced its real-time monitoring of production, ensuring high-quality, reproducible output and the flexibility to produce low-cost and small batches.

«When you visit American wineries, you immediately understand how good Americans are at selling their wine at a high price. To do so, they need excellent labels, and that's why we invested with a plant in Napa Valley»

«We have increased the quality of our products and the service level required by our global customers. [..]We need to achieve ever higher productivity standards to be competitive on the market. High productivity combined with excellent repeatable quality over time»

Firm D also invested in virtual reality, which allows clients to visualise their product designs on store shelves in 3D vis-a-vis rivals' products from the labels' design stage. Such technology has enabled the company to enhance its economic value and increase collaboration in the co-design process, allowing customers to better reflect their brand identity accurately through labels. Such competencies reside exclusively within the corporate headquarters, where international customers visit to engage in the label co-design process. Replicating these capabilities across foreign units would be impractical, as it would require duplicating a complex system of interdependent tasks, including the reproduction of digital label twins and their subsequent testing on advanced connected printing equipment.

Internationalisation. Firm D's international expansion began in 2007, and by 2023 around 45 % of its sales were generated from foreign sales revenues. The company's strategy has been based on foreign direct investments because proximity to clients is crucial for customising and co-designing labels.

Adopting digital offset printing and virtualisation technologies allowed Firm D to expand its international footprint by offering tailored, high-quality solutions to clients across the globe. The firm's focus on customisation and its advanced digital capabilities have been critical in maintaining its competitive edge in the global wine and spirits market. The firm's ability to produce country-specific editions for spirits, such as Tequila and Bourbon, has been a critical differentiator in these international markets.

«We print the classic stamps of import-export taxes, but also of alcohol selling tax. […] Such stamps must be unique because they are a certificate of payment. We have developed a software system for managing these codes to ensure total traceability. This is because our customers – often distilleries or alcohol producers – are less technologically advanced and struggle to manage these flows. It is also a marketing operation because our end customers appreciate the fact that, since we are technologically advanced, we take charge of a problem that they struggle to manage»

At the same time, Firm D highlights that virtual rooms for prototyping and design have their inherent technological limitations.

«We print labels for the very best products. The "initiation of a new design", that is to say, the industrialisation of a graphic concept, takes place in the presence of the client. During the COVID-19 pandemic, we virtualised this aspect, but as soon as it was possible, we returned to proof approval in person. Why? Packaging of a certain level that is composed of chromatic aspects but also of a tactile feeling needs to be verified at an emotional level; it is not a mechanical part that, once it is within tolerance, is fine»

As a consequence, nowadays, those designing stages where the emotional feel is crucial are managed in person, whereas the suitable stages (such as text modifications, benchmarking against competitors, and minor re-design due to products' evolution) are still handled

virtually.

Management's role. Although Firm D remains solidly under family ownership and control, assigning substantial importance to nurturing internal resources within its family culture, the company has appointed non-family managers in key roles to lead its digitalisation and internationalisation process. Along with external managers in the marketing, innovation, and business development departments, who provided expertise in implementing advanced technologies such as IoT and virtualisation, the introduction of an experienced Chief Information Officer (CIO) and a general manager proved fundamental.

In particular, the CIO led the uniformisation of the digital infrastructure to comply with the highest security standards and to standardise digital processes across the globe, which was a property's request for higher centralisation of governance. Instead, the general manager led the foundation for the Global Services offices, ensuring that the firm's digital initiatives aligned with its international expansion strategy.

> «There is a General Manager who built this [the Global Services]. He is our top manager, not a family member, and he also serves as the managing director of the Indian plant. It is the same person who put back on track the headquarters in California, who started the UK … in short, a person who has meant so much to the Eurostampa group»

The General Manager has been pivotal in introducing change management practices to dilute the internal resistance, made even more troubling by the acquisition of local firms in a technologically backward sector.

> «Almost all risks I see are due to change management and not the technologies themselves, that is, if I try to adopt a more advanced technology in a human context that is not ready and has not been properly accompanied, I can fail»

In conclusion, firm D's adoption of digital traceability, IoT-powered printing technologies, and virtual reality tools has enhanced its international performance. The company's ability to offer customised, high-quality labelling solutions has been a key factor in its success in global markets. The involvement of external managers has been crucial in guiding the firm's digitalisation and international investments and the organisational change they necessitate, ensuring that it remains agile and competitive in an increasingly globalised industry.

4.4.5. Firm E: AI-powered efficiency in spare parts distribution

I4.0 DTs adoption. Firm E, a small family business founded in 1963, specialises in the global distribution of spare parts for home appliances. Despite its modest size of around 50 employees, the company has expanded significantly over the 2020s, with 75 % of its sales now coming from international markets.

Firm E's advantage over international distributors lies in the superior knowledge of spare parts it has built over the years and has been sustained by investments in cloud-based big data solutions. Specifically, local distributors abroad have not mapped and codified spare parts in their product databases for the same variety of products and brands that Firm E has. Such knowledge covers items like the bill of materials for each model of white appliances commercialised by the leading international brands over the last 20 years, prediction analytics about their mean-time-between-failure, and the frequency of reorders by dealers or local distributors.

> «Our knowledge of spare parts, combined with predictive analytics, gives us a significant edge over local distributors»

This knowledge has progressively allowed the company to develop accurate demand forecasting algorithms and a more efficient inventory turnover. Such an advantage has recently been leveraged by investing in a broader automated warehouse that, in a single location and through AI algorithms, manages and automatises decisions about storage and picking paths based on the forecasted demand and orders received.

In addition to warehouse automation, Firm E launched a proprietary e-commerce platform powered by Application Programme Interfaces (APIs), enlarging the services offered to clients and customers.

> «Our system is in constant dialogue with 35 European distributors abroad, mainly from the Netherlands, the Czech Republic, Spain, France and Germany.
>
> [..]The API allows us to provide drop-shipping services to European distributors. These companies have a site that sells the products, but they do not have a warehouse. Their system surveys different suppliers and automatically makes decisions based on price, availability, and delivery time»

These platforms have improved the customer experience and allowed Firm E to expand its international reach by reducing reliance on local distributors.

Internationalisation. The firm exports to over 70 countries. Firm E's international growth has been driven by its superior product knowledge (spare parts), ability to leverage AI and automation solutions in inventory management, and a modular IT architecture that ensures high interoperability with smaller and local distributors' information systems. This bundle of technologies has allowed firm E to manage its global operations efficiently, with lower transaction costs with local distributors and a broader product variety.

Notwithstanding the undoubted advantages of digitalisation for the international positioning of Firm E, various operational risks and hurdles are worth noticing. Apart from the necessity to comply with norms about network information security and protect the digital infrastructure from cyberattacks, specific difficulties emerge from IT interdependencies and logistics that must deal with long distances and fast.

> «[Regarding the API]we are talking about end customers accustomed to Amazon's performance, so wherever you order today, it arrives tomorrow. We have to do the same on behalf of these companies.
>
> [..]We've gone from a few hundred API queries per day to millions. This has required paradigm shifts in servers, the cloud, transfer sizes and speeds, technology and dialogue between systems»

Management's role. Although Firm E remains family-run, the increasing complexity of its operations and reliance on AI-driven decision-making has required a shift in management.

> «Because of cultural reasons and our entrepreneurial experiences, we have the habit, especially on investments that exceed a certain amount, to maintain strategic control and a faster decision-making capacity typical of small-medium enterprises that allows us to make targeted, tailor-made projects. However, when these activities become more complex, managerialisation is necessary; we need expert figures who coordinate the internal resources to pursue objectives and the technology we acquire and, therefore, the external technological partners»

Consequently, Firm E hired an experienced manager who would act as a "director-general who oversees and coordinates resources in the various areas" and intensively interacts with the family ownership; a skilled IT manager to increase "control over IT choices and strategic activities"; and a data-analyst "who works entirely in support of sales, both for export and for the Italian market".

In conclusion, by optimising its warehouse operations and leveraging digital platforms, the company has efficiently managed its global supply chain and met the needs of international customers. To support such development, Firm E started a managerialisation and upgrading process that is still ongoing (the marketing director started an executive MBA program in 2023).

4.4.6. Summary

Table 5 summarises the most salient information we gathered from

Table 5
Summary table of the qualitative inquiry.

	Firm A	Firm B	Firm C	Firm D	Firm E
I4.0 DTs Adoption	Early adopter of virtualisation (3D CAD for virtual prototyping), blockchain for supply chain transparency, and laser bonding for sewing with recycled plastic	ERP and MES implementation; IoT and AI for smart warehouses and complex analytics; AR to reduce proximity needs; cybersecurity investment	Increased production control and quality management through MES, traceability system and advanced manufacturing	Digital traceability; advanced IoT-powered printing machines; virtualisation for co-design and visualisation centralised in the corporate parent.	AI-powered demand forecasting; warehouse automation; API-driven e-commerce in the presence of more modular IT architectures
Internationalisation	95 % of production exported to luxury industry leaders; reputation premium for being tech-savvy and sustainable	35 % export share; international growth constrained by need for local partners and adequate commercial skills; private equity investment for global expansion	65 % export ratio; vertical integration of production stages attracted international clients	45 % sales from exports; direct investments in France, Scotland, the USA, Mexico, and India	75 % international sales; strong digital infrastructure but cybersecurity and logistics challenges
Management's role	Non-family CEO introduced digitalisation and professionalisation; difficulty in workforce upskilling for 3D; strategic misalignment with traditional clients	Family CEO with external managers in leading roles; restructuring to enhance global competitiveness	Family CEO with external manager for lean manufacturing; new external managerial roles in quality, security, and sustainability; cultural resistance to digitalisation	Family ownership; non-family general managers led change in the organisational structure to introduce centralisation through "global business services"; non-family CIO and managers in innovation, marketing and business development	Family-run but increasing managerialisation; external director-general, IT manager and data-analyst.

the case studies along the three dimensions relevant to our enquiry: I4.0 DTs adoption, Internationalisation, and Management's role.

5. Discussion

The I4.0 DTs hold significant potential to support firms in their internationalisation efforts by simplifying processes related to "being abroad" and international customer collaboration. However, processes' digitalisation might bring cybersecurity, operational and strategic risks (Kessler et al., 2022; Parent and Reich, 2009) that require the development of the necessary digital capabilities, advanced management skills and new organisational processes. Such a challenge has been depicted as a relevant domain of the firm's dynamic capabilities (Teece, 2007).

In this paper, we examine the role of TMT characteristics in shaping the relationship between digitalisation and internationalisation. Specifically, we posit that family management negatively moderates the positive effects of digitalisation on international performance, as this type of management is often linked to more insular thinking (Calabrò et al., 2019; De Massis et al., 2015), a tendency to preserve the status quo to safeguard the family legacy in response to radical technological changes (Ceipek et al., 2021; Daspit et al., 2018; Miller et al., 2011) and a less diverse and specialised TMT (Chrisman et al., 2013; Duran et al., 2016; Matzler et al., 2015). Such characteristics determine how governance mechanisms anticipate and manage the risks associated with digitalisation (Yeow et al., 2018).

The results indicate that the adoption of I4.0 DTs between 2015 and 2017, coinciding with the emergence of the I4.0 largely due to supportive public policies towards their adoption (Cefis et al., 2025; Cirillo et al., 2023), led to an increase in foreign sales per employee, and family management was found to moderate the impact of digitalisation on international performance negatively. After pruning the analysis from ex-ante observable differences between firms adopting I4.0 DTs and those that did not, such an effect is robust for information I4.0 DTs (big data analytics, augmented reality, and the IoT), while it is not statistically significant in the case of advanced robotics adoption.

One possible explanation for the inefficacy of robotics is related to the timing of our survey, which collected data about the last three years' investments in 2018. The investments in robotics recorded in the survey might involve the expansion or renewal of already existing production facilities rather than an effort to manage market diversity and logistical hurdles by reducing asset specificity and increasing operational flexibility through interconnected, advanced robots (D'Aveni and Venkatesh, 2020; Li et al., 2021). If investments in interconnected machines are not accompanied by organisational and strategic changes in how the firm creates and delivers value to international clients, their impact on value capture through sales abroad may remain limited.

Coherently with such results, the negative moderation of family management emerges only on information I4.0 DTs rather than robotics. Indeed, compared to robotics, the implementation of I4.0 DTs adds complexity to the organisation (Ceipek et al., 2021). It requires more system-level changes in the organisational and business model of the firm to accommodate the potential of a data-driven decision process (Colombari et al., 2023; Frank et al., 2019). Thus, our findings confirm that the complexity of these technologies requires specific knowledge and managerial competencies that are frequently lacking in firms managed by families (Bornhausen and Wulf, 2024; Ceipek et al., 2021; Cirillo et al., 2023). By contrast, our findings align with the notion that production I4.0 DTs in production primarily introduce operational rather than strategic risks. Operational risks tend to be managed through vendor support agreements and operational routines involving only middle management at the plant level, thus requiring minimal additional managerial resources. Consequently, these risks may be relatively independent of the strategic capabilities of the TMT.

Furthermore, in contexts characterised by high product variety and the necessity for market adaptation driven by internationalisation, production I4.0 DTs facilitate the centralisation of diversified production activities at the corporate level, owing to the lower asset specificity associated with these technologies. Firms operating internationally with production units abroad often prefer centralising the deployment of novel production assets within their primary facilities. This approach enables companies to adopt such investments incrementally, minimising the complexities and interdependencies that would arise if the technologies were replicated simultaneously across multiple international

units. Taken together, the centralisation choices associated with novel production I4.0 DTs do not generate a demand for additional novel managerial resources. Such a consideration helps explain why the presence of non-family management does not positively moderate the relationship between the adoption of production DTs and international performance.

Our qualitative inquiry provides more profound insights into the causal mechanisms linking digitalisation efforts, international performance, and management characteristics. While the quantitative analysis identifies average effects and moderating relationships across a large and representative sample, the case studies explore the underlying dynamics: the organisational conditions under which DTs complement each other, and how managerial structures shape implementation pathways. The qualitative findings expand and contextualise the statistical results, offering a more granular understanding of how digitalisation and management interact in practice.

Across all five firms, digitalisation initiatives directly impacted internal performance through increased efficiency, operational flexibility, market agility, traceability, responsiveness, and customisation. Firms A and E leveraged virtual prototyping and AI-based inventory automation, respectively, to accelerate product delivery and lead time. Firms B and C introduced MES integrated with ERP systems that enhanced resource planning, quality assurance, and cost control on a more granular level. Firm D, meanwhile, integrated digital traceability and virtualisation tools to maintain consistent quality and co-design capabilities across globally dispersed production sites.

In line with the underpinning of dynamic capabilities (Lee et al., 2015; Sambamurthy et al., 2003; Verhoef et al., 2021), all cases underscore the centrality of management quality in shaping the effectiveness of digital transformation. Firms that achieved the most significant performance improvements had hired external managers with digital, operational, or international expertise. Firm A's transition from a family-led structure to a professionalised management team, including a non-family CEO and specialised roles such as an ICT manager, was crucial in both identifying opportunities for innovation valuable to customers and in changing the organisational structures and processes, starting a codification and standardisation of previously informal processes and enabling the firm to scale internationally. Similarly, Firm B underwent a gradual managerial transition culminating in a post-capitalisation effort to strengthen its TMT. To sustain technology adoption aimed at improving OEE, Firm C recruited a senior quality manager with experience at a key client in introducing lean thinking and integration logics in all the manufacturing and quality management processes. In Firm D, the general manager and CIO, both external to the founding family, led the global centralisation of the digital and governance structures needed to introduce virtualisation and ensure product development and manufacturing integration. Firm E, though still family-led, has begun a process of managerialisation and introduced senior roles to handle technological complexity, such as a general director and specialised data analyst roles.

Hence, external managers often acted as enablers of sensing opportunities (e.g., global market demands for traceability and speed), seizing them through appropriate investments and process redesigns (e.g., MES, APIs) and transforming organisational processes and structures (e.g., new decision-making processes, codified workflows, or change management initiatives). These managerial interventions were not merely technocratic in nature. In Firm A, the CEO could balance the tensions between digital skills and the legacy of artisanal craftsmanship. In Firm D, change management and a global vision on the centralisation of some processes and technology adoption were explicitly highlighted as being more critical than the deployment of technologies. In Firm C, the lack of digital fluency at the operational level created vulnerabilities that only structured managerial efforts, such as process training, new middle management roles, and lean programs, could mitigate.

In multiple cases, hiring external managers not only supported the transformation process required by technology adoption but also enhanced the firms' attractiveness and credibility in international markets. Non-family managers signalled to large and international customers the firm's capacity to seize the opportunities of I4.0 DTs, manage their complex integration, and use them for an agile business model in international markets. For example, in Firm A, the appointment of a non-family CEO played a decisive role in mitigating the firm's liability of foreignness (Denk et al., 2012; Zaheer, 1995) when engaging with new international customers and convincing them about the firm's digital capabilities to adopt and integrate I4.0 DTs to support product virtualisation and granular control of logistic flows. Similarly, Firm B's transition to a more professional managerial structure was explicitly validated by the private equity fund, which assessed the firm's readiness to internationalise based on its TMT. The fund's post-investment strategy focused on further enhancing international sales capabilities through professional recruitment, necessary to manage a larger volume of clients' data and provide higher-value-added services. Firm D's general manager, instrumental in launching international operations and leading digital convergence, was credited with enhancing internal efficiency and instilling trust across the global organisation and clients in technologically backward segments. Likewise, the CIO's work in global digital standardisation responded to client demands for secure and consistent infrastructure across sites. Such evidence suggests that managerial professionalism, particularly when aligned with digital maturity, signals reliability and legitimacy to international partners, complementing technological differentiation.

By cultivating a reputation for innovation, external managers help build trust with foreign customers – particularly important in contexts marked by information asymmetries. This trust enables collaborative learning, a key mechanism for developing dynamic capabilities, through which firms and customers jointly explore the application of I4.0 DTs to integrate product development, manufacturing, and quality management. These observations resonate with research suggesting that international partners and clients perceive professionalised firms as more trustworthy and capable of meeting complex standards and compliance requirements (Banalieva and Dhanaraj, 2019), which are increasingly important in driving the use of I4.0 DTs.

The case studies help unpack the nature of family management, illustrating why it is not an on-off condition but a governance continuum. Transitioning from family to non-family management involves the progressive integration of external expertise across different layers of the firm, not only at the CEO level but also through digital officers, functional chiefs, and middle managers. This perspective helps to open the "black box" of family management, whose heterogeneity cannot be captured by firm-level quantitative measures. The case studies also help formulate an additional explanation for our quantitative findings about the lack of significant impact of advanced robotics adoption on internationalisation. Specifically, case studies illustrate that advanced robotics generates its full value when used in conjunction with advanced real-time monitoring and tracking through sensors and AI for quality management, data analytics for (automatic) warehouse optimisation and virtualisation tools for digital designing (Porter and Heppelmann, 2015; Shleha et al., 2023). The case of Firm E, in particular, indicates that when the adoption of robotics and automation systems in production and inventory management was accompanied by investments in MES technologies and a modular plug-and-play digital architecture, the firm could count on an increased data granularity and volume, and more integration of information flows with foreign distributors to support a model based on quick delivery of small orders. On the contrary, the

effects of robotics were limited when such initiatives were implemented in isolation, without the broader "datification" of production and operational activities (Frank et al., 2019). Without integration, robotics investments may primarily serve to upgrade production capacity, but this has no direct and salient effects on the agility of firms in international markets.

6. Conclusions, limitations and future research avenues

Our work advances the international studies literature in several ways. First and foremost, we provide an empirically robust econometric analysis showing that adopting I4.0 DTs enhances international performance, which was previously stated but seldom tested rigorously on a large and representative sample of firms (Bergamaschi et al., 2021; Cassetta et al., 2020; Dagnino and Resciniti, 2021; Hervé et al., 2020; Zheng et al., 2023; Zhou and Xu, 2024). Moreover, we can separate information and production I4.0 DTs and find an international performance enhancement only from the adoption of information I4.0 DTs.

Furthermore, our findings contribute to the literature on the role of the TMT, particularly in family businesses (Ceipek et al., 2021; Cuypers et al., 2022; J. De Groote et al., 2023), by quantitatively exploring whether the presence of family management, proxying the TMT's capacity to handle risks arising from digitalising processes, moderates the effect of investing in I4.0 DTs (Calabrò et al., 2019). From a theoretical perspective, our results highlight the challenge of adopting I4.0 DTs by underscoring the importance of building dynamic capabilities (Verhoef et al., 2021; Yeow et al., 2018). Because these technologies are pervasively integrated into core organisational processes, their effective adoption demands a broader range of competencies, specialisations, and roles within the TMT – particularly in family firms.

Family management can lead to strategic and action inertia, slowing decision-making, digital adoption and transformative initiatives that can support the firm in international markets (Ceipek et al., 2021). Also, our quantitative results reveal that family firms tend to have lower educational qualifications within their workforce. Such findings confirm a weakness in the family firm's ability to attract and develop highly qualified human capital, which, combined with less specialised family management, helps explain the lower returns these firms experience from digital adoption. Finally, non-family managers can develop a superior strategic foresight about digital opportunities and risks thanks to the capability to build open governance structures like the involvement of external advisory board members with digital experience (Lanzolla et al., 2021). In other words, non-family managers often have a heightened ability to sense and seize digital opportunities and anticipate risks (Bornhausen and Wulf, 2024; Hillebrand et al., 2020).

Future research could explore further mechanisms. In particular, the recent literature on family businesses has delved into the heterogeneity within family firms, such as the interplay between property and management (Bornhausen and Wulf, 2024; D'Angelo et al., 2016). Future studies could explore how such an interplay moderates the effectiveness of digital investments and, in particular, the readiness to change work routines. Another promising development regards surpassing the focus on the TMT and shifting to the role of middle managers or functional leaders in translating digital strategies in family or non-family-managed firms.

In five case studies, we enrich our quantitative results with qualitative exploratory evidence about the mechanisms I4.0 DTs deploy their effects and the enabling role of the management's composition. The qualitative investigation raises interesting avenues for future research. For example, our evidence calls for attention to the social capital of non-family CEOs, for example in terms of reputation and credibility (Blumentritt et al., 2007; Calabrò et al., 2019; Deephouse and Jaskiewicz, 2013). A non-family, experienced CEO can lend credibility to digital initiatives, helping to engage large international customers even without a consolidated track record in the firm's digital ventures.

Our study is not free of limitations. Even though the quantitative analysis builds on a large dataset, it focuses on Italy and collects information about I4.0 DTs adoption before 2018. Given the rapid pace of I4.0 DTs development and the variety of their adoption across countries, a vaster geographical scope and more recent time frame would be beneficial. Comparative studies in institutional contexts with different governance structures and digital policy regimes would test the boundary conditions of our findings and broaden their relevance. Furthermore, we cannot explore the role of TMT's compositional characteristics, such as non-family members' background and career stage, or dimensions of the board's functioning, such as roles' division in strategic decision-making (Calabrò et al., 2019; Filatotchev et al., 2023). Future quantitative research on this venue might deliver further insights into our findings' underlying mechanisms. Similarly, although we enrich the literature by exploring information and production I4.0 DTs separately, the binary nature of I4.0 DTs adoption limits our ability to differentiate between firms with superficial versus deep integration. Such a simplification may dilute the observed effects, especially regarding robotics. Even though we try to amend such a limitation with the qualitative analysis, a more profound quantitative account of digitalisation is due.

Our findings carry insightful implications for managers. Firms should prioritise the integration of information and production I4.0 DTs, as their combined use enables the orchestration of complex international operations through enhanced coordination, responsiveness, and data-driven control. Treating these technologies as complementary – rather than pursuing them in isolation – unlocks their full potential in supporting international competitiveness. Moreover, firms should invest in the professionalisation of their managerial structures, particularly by incorporating external managers with diverse experience and digital competencies. These profiles are better positioned to build the dynamic capabilities required to continuously adapt organisational processes, mitigate the risks of digitalisation, and align digital initiatives with international growth strategies. Finally, managers should adopt collaborative learning with international clients as a deliberate strategic approach. Building trust through a reputation for digital competence facilitates joint problem-solving and knowledge exchange, which are critical mechanisms for sensing opportunities and renewing capabilities in rapidly evolving technological and market environments.

Important implications for public policy arise. Over the past few decades, numerous government programs, such as those dedicated to Industry 4.0 and 5.0, have allocated resources to support digitalisation. However, many of these initiatives failed to consider the organisational and managerial contexts in which digital projects were implemented. Our findings suggest that policymakers should ensure that support for digital transformation addresses the managerial and governance needs critical to successful implementation and international competitiveness.

CRediT authorship contribution statement

Paolo Neirotti: Writing – original draft, Methodology, Investigation, Conceptualization. **Andrea Ricci:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Matteo Tubiana:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

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Appendix

A.1 More about data

A.1.1. RIL-INAPP

The RIL-INAPP survey is included in Italian SISTAN, and its representative sample is stratified by size, sector, geographical area, and firm legal form. For more details on the RIL questionnaire, sample design and methodological issues, see https://www.inapp.gov.it/rilevazioni/rilevazioni-periodiche/rilevazione-imprese-e-lavoro-ril.

A.1.2. Definition of I4.0 DTs in the survey questionnaire

As a note to the survey question regarding digital investment made, the survey provides the following definitions:

"*The Internet of Things,* also known as web 4.0, refers to objects that communicate in real-time with other objects, updating their respective operational routines. It is based on fundamental technologies such as sensor networks and radio frequency transmitters (RFID tags).

Big Data refers to the availability of both physical and intangible means that allow the storage, processing, and transmission of enormous masses of data, with the underlying technology being data storage on RAM instead of on disk.

New-generation industrial *robots* and service *robots* are designed to work alongside humans and are specialised in performing specific tasks. They are automatically controlled, reprogrammable in three or more axes, and can be either stationary or mobile. They are used in industrial automation applications, often for repetitive and wear-intensive tasks assigned to robots to increase production line efficiency (e.g., robotic welding, laser cutting, spray painting, etc.).

Augmented reality and virtual reality involve the enhancement of human sensory perception through information, typically manipulated and conveyed electronically. The elements that "augment" reality can be added through a mobile device, such as a smartphone, using a PC equipped with a webcam or other sensors, with vision devices (e.g., retinal projection glasses), hearing devices (earphones), and manipulation devices (gloves) that add multimedia information to the reality already normally perceived.

New-generation industrial robots are designed to work together with man and are specialised in carrying out specific tasks; they are automatically controlled and reprogrammable in three or more axes, can be fixed or mobile, and are used in industrial automation applications. Collaborative robots have a certain degree of autonomy and can operate in a complex and dynamic environment requiring interaction with people, objects or devices (for example, construction, cleaning, transport, surveillance, security, etc.)."

A.2 Further descriptive statistics and results

Table A 1
Descriptive statistics by corporate governance. Average values.

	Family management	No-family management
	Foreign markets and I4.0 DTs	
Foreign markets (0/1)	0.287	0.310
% sales from foreign markets	8.635	12.556
Log of sales from foreign mkt pc	2.900	3.332
At least one I4.0 DT	0.135	0.179
Information I4.0 DTs	0.105	0.151
Robotics	0.052	0.046
TMT characteristics		
Tertiary education	0.207	0.452
Upper secondary education	0.548	0.492
Female	0.145	0.108
Workforce composition		
Share of tertiary education	0.087	0.194
Share of upper secondary education	0.477	0.540
Share of lower secondary education	0.436	0.267
Share of aged workers	0.231	0.286
Share of middle-aged	0.476	0.483
Share of executives	0.033	0.086
Share of white collars	0.363	0.534
Share of blue collars	0.604	0.380
Firm characteristics		
Multinational ownership	0.002	0.170
Employers' association	0.606	0.664
Firms age (in years)	26.84	27.72
Product innovation	0.373	0.449
Process innovation	0.325	0.317
Log of number of employees	2.446	3.030
N of obs	7164	1398

Source: authors' calculations on RIL longitudinal sample. Note: pooled 2010-2015-2018 data. Sampling weight applied.

Table A 2
Estimates Diff-in-Diffs FE. Dependent variable: the probability of internationalisation.

	[1]	[2]	[3]
DT*year2018	0.027**		
	[0.009]		
DT*year2014	0.003		
	[0.019]		
Information DT*year2018		0.032*	
		[0.019]	
Information DT*year2018		0.005	
		[0.019]	
Robotics*year2018			0.004
			[0.014]
Robotics*year2014			0.002
			[0.022]
Year2018	0.006	0.006	0.011
	[0.009]	[0.009]	[0.006
Year2014	0.009	0.008	0.009
	[0.006]	[0.008]	[0.004]
FM	−0.012	−0.012	−0.013
	[0.028]	[0.022]	[0.029]
Constant	0.363***	0.363***	0.362***
	[0.013]	[0.033]	[0.013]
Other controls	Yes	Yes	Yes
N of Obs	8562	8562	8562
N of Firms	3186	3186	3186
R2	0.736	0.74	0.735

Note: All regressions include interactions between 2-digit sectors and NUTS2 regions and firm size (in classes) FE. Robust standard errors in parentheses are clustered at the firm level. Statistical significance: *** at 1 %, ** at 5 %, * at 1 %.
Source: author's elaborations on RIL-ORBIS data.

Table A 3
Quality of the matching procedure. Balance property.

	Matched/unmatched	Mean		% bias	% bias reduction	T-test	
		Treated	Control			T	P > t
TMT characteristics							
Tertiary education	U	0.397	0.291	22.5		8.66	0.000
	M		0.410	−2.81	87.5	−0.81	0.417
Upper secondary education	U	0.455	0.503	−9.6		−3.61	0.000
	M		0.444	2.2	76.9	0.67	0.505
Age in years>55	U	0.334	0.347	−2.7		−1.01	0.312
	M		0.339	−1.0	61.1	−0.32	0.752
Female	U	0.094	0.124	−9.7		−3.54	0.000
	M		0.089	1.6	83.6	0.52	0.604
Family management	U	0.791	0.851	−15.7		−6.16	0.000
	M		0.783	2.2	86.3	0.61	0.544
Workforce characteristics							
Share of graduate	U	0.145	0.105	21.8		8.36	0.000
	M		0.147	−0.8	96.3	−0.23	0.815
Share of upper secondary	U	0.457	0.447	4.0		1.45	0.146
	M		0.453	1.8	55.4	0.58	0.564
Share of executives	U	0.051	0.041	11.0		4.22	0.000
	M		0.052	−1.1	90.5	−0.33	0.745
Share of white collars	U	0.384	0.354	10.7		4.01	0.000
	M		0.391	−2.3	78.5	−0.71	0.48
Firms characteristics							
Multinational	U	0.068	0.026	19.7		8.55	0.000
	M		0.086	−8.9	55.0	−2.12	0.034
Employers' membership	U	0.764	0.683	18.3		6.72	0.000
	M		0.770	−1.2	93.2	−0.39	0.695
Firms age (in years)	U	32,05	29,932	12.5		4.71	0.000
	M		32,647	−3.5	72.1	−0.98	0.329
Product innovation	U	0.663	0.362	63.2		23.76	0.000
	M		0.649	2.9	95.4	0.87	0.383
Process innovation	U	0.650	0.333	67		25.35	0.000
	M		0.638	2.6	96.2	0.76	0.446

Note: tests for each sector, firm size in classes, and NUTS2 region are omitted for brevity. They are available upon request.
Source: author's elaborations on RIL-ORBIS data.

Table A 4
Estimates of Diff-in-Diffs with FE. Dependent variable: (log of) sales from international markets per capita. The estimation sample is restricted to "first adopters" (firms that did not invest in ICTs in the previous period).

	[1]	[2]	[3]
DT*year2018	0.538*		
	[0.175]		
DT*year2014	0.502		
	[0.276]		
Information DT*year2018		0.534*	
		[0.286]	
Information DT*year2014		0.351	
		[0.276]	
Robotics*year2018			0.483
			[0.211]
Robotics*year2014			0.686
			[0.503]
Year2018	0.144	0.163	0.197
	[0.143	[0.117	[0.120]
Year2014	0.166	0.201**	0.200**
	[0.091	[0.102]	[0.045]
FM	−0.018	−0.030	−0.020
	[0.227]	[0.301]	[0.234]
Constant	2.626***	2.639***	2.605***
	[0.252]	[0.433]	[0.227]
Other controls	Yes	Yes	Yes
N of Obs	4949	4949	4949
N of Firms	1857	1857	1857
R2	0.724	0.733	0.724

Note: All regressions include interactions between 2-digit sectors and NUTS2 regions and firm size (in classes) FE. Robust standard errors in parentheses are clustered at the firm level. Statistical significance: *** at 1 %, ** at 5 %, * at 1 %.
Source: author's elaborations on RIL-ORBIS data.

Table A 5
Definition of variables.

	Main variables
Foreign markets	The dummy variable equals 1 if the firms sell (export) their products/services in international markets, 0 otherwise.
% Sales foreign markets	(Log of) Total sales (in euros) derived from selling products/services in international markets (per employee). The amount of sales is deflated.
At least one I4.0 DT	The dummy variable equals 1 if firms adopted at least one digital technology (IoT, big data analytics and augmented reality, robotics) over the period 2015–2017, 0 otherwise.
Typologies of I4.0 DTs	Two dummy variables indicating firms' investment over the period 2015–2017 in: i) information I4.0 DTs (IoT, big data analytics and augmented reality), ii) production I4.0 DTs (robotics); 0 otherwise.
Management and corporate governance	
Managers' education	Three dummy variables that equal to 1 whether the educational level of who runs the firm is: i) tertiary; ii) upper secondary; iii) lower secondary or elementary, 0 otherwise.
Managers' female	Dummy variable equals 1 whether the entrepreneurs/managers who run the firm are female, 0 otherwise.
Family management	The dummy variable equals 1 if the firm is managed by an individual who also owns the firm and/or is selected dynastically by the family ownership, 0 otherwise.
Workforce composition	
Education	Three variables indicating the share of employees (on the firm's total number of employees) with i) tertiary education; ii) upper secondary education; iii) lower secondary or elementary.
Professional status	Three variables indicate the share (on the firm's total employment) of: i) executives, ii) white collars, and iii) blue collars.
Firms characteristics	
Product innovation	The dummy variable equals 1 if the firms invested in new products and services in a three-year period before the survey, 0 otherwise.
Process innovation	The dummy variable equals 1 if the firms innovated productive processes in a three-year period before the survey, 0 otherwise.
IRAP tax cut	The dummy variable equals 1 if the regional production tax (Imposta Regionale sulle Attività Produttive, IRAP) cut influenced investment decisions in the 2015–2017 period, 0 otherwise.
Employers' association	Dummy variable equals 1 if the firm is a member of an employer's association, 0 otherwise.
Multinational ownership	Dummy variable equals 1 if the firm belongs to an international group, 0 otherwise.
Firm's size	Four classes are classified according to the total number of employees: [0–9], [10–49], [50–249], and more than 250 employees.
Firm's age	(Log of) Number of years since the firm has been funded.
Geographical localisation	20 dummy variables indicating the Italian NUTS2 regions.
Sector of activities	85 dummy variables indicating extra agricultural 2-digit sectors of activities from ATECO classification (Italian National Institute of Statistics, ISTAT)

Source: RIL Data.

Data availability

The authors do not have permission to share data.

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