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The impact of business owners' individual characteristics on patenting in the context of digital innovation

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ABSTRACT

As digital transformation accelerates, generating demand for new digital products, processes, and technologies, it is necessary to create consensus among all the actors involved on the company's digital innovation strategies. Owners greatly influence a company's objectives and design: they represent a group to which the top management must pay particular attention. Understanding which individual aspects of the owners influence digital innovation processes becomes very important. However, studies on the impact of owners' characteristics on digital innovation are rare. This article analyzes over 550 patent-holder firms engaged in digital innovation to fill this gap. The study evaluates the relationship between owners' characteristics and patenting activity. The results show a significant impact of gender diversity, education, and minority status of the owners on digital innovation. By favoring a deeper understanding of the profile of owners concerning digital innovation, the findings of this study help top management identify more effective engagement strategies for a better performance of the digital transformation process.

1. Introduction

The availability of new digital technologies drives digital transformation. In turn, it creates demand for innovation, thus generating a virtuous circle (Enkel et al. 2020). Digital innovation has been defined as creating (and the consequent change in) market offerings, business processes, or models that result from digital technology (Nambisan et al., 2017). It includes the development of new technologies (Benassi et al. 2020; Glinkina et al. 2020), as well as their incorporation into new products and services (Johansson et al. 2021), and in general, the learning processes through which organizations digitally transform themselves (Selander et al. 2013; Laurenza et al. 2018).

As the global impact of digital transformation increases (Bresciani et al., 2018; Verhoef et al., 2019), more and more scholars are devoting themselves to analyzing innovation processes related to digital technologies (Hess et al., 2016; Bertello et al., 2020; Annarelli et al. 2021). Understanding the factors that influence the effectiveness of digital innovation processes is of paramount importance (Annarelli et al., 2021). The scientific literature has identified numerous factors that influence the effectiveness of digital innovation processes: at an institutional (Wei et al. 2022), organizational (Cheng and Wang, 2022), team (Ardito et al. 2021), and individual level (Opland et al. 2022).

Existing studies highlight how the aspects at the individual level, i.e., the characteristics of the people involved in digital innovation processes, are particularly relevant. For example, Firk and colleagues (2021) have studied the role of top managers, finding that their characteristics have a relevant impact on the success of digital innovation initiatives. Several studies analyze the individual traits of inventors (Goel & Göktepe-Hultén, 2021; Link & van Hasselt, 2020). Others have investigated the role of different categories of individual actors like entrepreneurs (Hevner and Gregor, 2022), investors (Müller et al. 2019), and external experts (Martinez-Corral et al. 2019).

The individual aspects are the micro-foundations on which innovation processes are based (Steinhauser, 2021). Besides, the discussion above underlines several categories of individual stakeholders – e.g., managers, investors, inventors - are involved. For each stakeholder

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category, it is necessary to study which characteristics are relevant and how they impact the process.

Business owners, in particular, represent a category of individuals with a strong influence on the performance of organizations (Fairlie and Robb, 2009). They indirectly influence the company's operation, acting on top management (Mio et al. 2016) and directly expressing preferences on strategic choices (e.g., Liu et al. 2015). In digital innovation and Industry 4.0, owners have a more significant impact since processes are typically less structured, and top levels need to support an entrepreneurial attitude (Bartoloni et al. 2021). In this context, it is clear that the role of governance is fundamental for enabling behaviors that promote innovation.

It has been found that the personal characteristics of the owners have an impact on the decisions they make regarding the company (Melissen et al., 2016) and, consequently, on the functioning of the organization (Botero and Velez, 2018) and its performance (Simo Kengne, 2016).

Their importance notwithstanding, individual aspects - i.e., the contribution of human factors to an effective business transformation - are probably the least studied among the antecedents of practical digital innovation (Zimmermann et al., 2020; Picone et al., 2021). The role of owners in digital innovation is even less investigated (Ano and Bent, 2021; Corvello et al., 2021).

Considering, therefore, the need for studies on digital innovation, the relevance of the role of owners, and the simultaneous lack of studies on owner characteristics as antecedents of digital transformation, there is a manifest need to investigate the impact of individual aspects of owners on digital innovation.

To fill the above gap, this paper addresses the following research question:

R.Q.: What individual characteristics of owners significantly impact digital innovation output?

The central argument in this study is that the individual characteristics of the owners condition their attitude towards company objectives and organization (Kouki, 2021; Sikavica et al., 2020). In particular, these aspects affect how owners conceive and interpret digital innovation processes (Kindermann et al., 2021; Hassan et al. 2021). In other words, depending on personal traits such as gender (Marcel, 2009; Ruiz-Jimenez et al., 2016), or experiences such as education (Liu et al. 2018) or belonging to a minority (Jones, 2008), owners can prove to be more or less sensitive to the objectives of digital transformation.

Based on these arguments, a sample of over 550 companies was obtained from the Orbis - Bureau Van Dijk (BVD) database (https://www.bvdinfo.com/en-gb/our-products/data/international/orbis). The companies were selected based on their engagement in digital innovation as patent holders in Industry 4.0. The data on owners' characteristics and patent productivity were analyzed using Multiple Linear Regression with diagnostic checks of Gauss–Markov assumptions (Aiken and West, 1991; Baron and Kenny, 1986; Cohen et al., 2003; Hayes and Cai, 2007; Hayes and Matthes, 2009; Poole and O'Farrell, 1971; Wooldridge, 2010).

Stakeholder theory (Freeman, 1984) has highlighted top managers' responsibility to involve and influence owners to favor consensus and the achievement of corporate objectives (Chams and García-Blandón, 2019, Serravalle et al., 2019). Understanding the owners' characteristics is essential to guide a company towards effectively implementing any strategy (Laplume et al. 2008), including digital innovation processes and digital transformation (Barrane et al. 2021). Again, the importance of governance in addressing the company in pursuing innovation pathways has to be underlined. The results of our study highlight personal aspects of owners - namely gender, education, and belonging to a minority – that positively impact the company's output in digital innovation. These results help define an owner profile favorable to digital innovation. The definition of this profile is the first step to designing strategies of involvement and communication by top management with the ultimate aim of accelerating innovation and digital transformation.

The article is structured as follows. The next section briefly summarizes the literature on digital innovation and the role of owners' characteristics. The methodology used is then detailed. Results and their discussion follows, then the conclusions with implications and indications for future research.

2. Theoretical background and research hypotheses

2.1. Digital innovation and Industry 4.0

Digital innovation understood as the creation of (and the consequent change in) market offerings, business processes, or models that result from the use of digital technology (Nambisan et al. 2017), is a fundamental component of digital transformation, as highlighted by the digital transformation of the economy or society as a whole: digital innovation, introducing or improving products and services based on digital technologies, is the engine of change (Vega and Chiasson 2019; Glinkina et al. 2020). Digital innovation also plays a fundamental role at the company level. Abrell et al. (2016) show how a company can have a passive or proactive role in digital transformation and how the ability to create innovative solutions becomes fundamental. Similarly, Jafari-Sadeghi and colleagues (2021) distinguish three aspects of digital transformation at the enterprise level: preparedness, digital technology exploration (e.g., research and development), and digital technology exploitation (e.g., patents and trademarks). The authors found a positive relationship between patent applications, technology entrepreneurship, and technological market expansion. In addition to a direct link between digital transformation and digital innovation (i.e., digital innovation is a component of digital transformation), there is also an indirect one. Digital innovation has been conceptualized as capabilities necessary to lead a successful change. Hence, by experiencing innovation processes, organizations acquire skills to improve their digital products and processes and, ultimately, their performance (Selander et al. 2013; Laurenza et al. 2018).

The challenge of digital innovation is particularly relevant for manufacturing companies (Abrell et al. 2016), committed to integrating digital technologies with physical products and processes according to the Industry 4.0 paradigm (Johansson et al., 2021). Both large and small and medium-sized manufacturing companies undertake a complex digital innovation path to adapt to the paradigm of Industry 4.0 and exploit its advantages (Elia et al. 2021; Del Giudice et al. 2021).

In this context, the issue of intellectual property - e.g., patent protection - takes on a more relevant dimension than in service companies (Jafari-Sadeghi et al. 2021), even if the two sectors of activity increasingly converge - i.e., servitization (Kim et al. 2019; Frank et al. 2019). The study of patent data for novel digital technologies is instrumental in understanding the nature and dynamics of innovation processes (Pezzoni et al., 2022), namely in the digital transformation and Industry 4.0 domains, whereas patent activity is a proxy for digital innovation (Ahn, 2020; Wang and Hsu, 2021; Jemala 2021). Recent studies report a significant increase in patents and patent-based competition for Industry 4.0 technologies (Benassi et al. 2020; Chih-Yi and Bou-Wen 2021). In this context of hyper-automation and hyperconnectivity, with a high pace of innovation rate, the dynamics related to patent litigation, patent protection, and strategic patenting prove that attacking firms perform better (Chih-Yi and Bou-Wen, 2021). Boudreau et al. (2022) show that digital innovations can be effectively protected by combining patents and copyright, which cover digital product design and digital content. Uriarte et al. (2022) explored the dynamics of patenting activity in the field of sustainability of agri-food chains oriented toward Industry 4.0, while Tirgil and Findik (2022) found that awareness of Industry 4.0 applications positively affects firms' innovation performance. Nylund and Brem (2021) analyzed a patent dataset to investigate the relationships between open innovation at large and innovation performance, proving that only digital innovation is significantly affected by open innovation, as openness and context-related factors leverage the peculiar characteristics of digital solutions (Annarelli et al. 2021; Chih-Yi and

Bou-Wen 2021; Boudreau et al. 2022).

Annarelli et al. (2021) suggest that a research effort is needed better to understand the nature of digital innovation and related capabilities. In the area of Industry 4.0, analyzing firms' patent productivity and associated factors is an essential starting point. As illustrated in the next section, the human characteristics that distinguish business owners can significantly influence them, and we focused on them in this study.

2.2. Owners' characteristics

There is a consensus that the human factor remains essential also in the fourth industrial revolution context. Neumann et al. (2021) proposed a framework for successful digital transformation processes that systematically considers human factors in Industry 4.0 design and implementation. The personal characteristics at the top-level impact relevantly on innovation activity.

Even if this paper is focused on the impact of owners' characteristics on patenting, to give a complete overview of the phenomenon, in this section, some attention is devoted to the individual elements of other stakeholders who are often involved in the process of innovation and particularly top management.

Between business owners and top management, there is a close relationship: business owners act on top management to influence the activity of the company (Mio et al. 2016), and top management is called upon to involve owners to favor consensus and the achievement of corporate objectives (Chams and García-Blandón 2019, Serravalle et al. 2019).

The individual characteristics of top managers are relevant for a large number of processes related to digital transformation (Elbanna & Newman 2022): the entire management team impacts significantly on the success of digital innovation initiatives (Firk et al. 2021) and exerts a significant influence on the context of innovation processes – i.e., company strategies, human resources management policies, and research and development.

The identity of founders was studied to understand how firms organize digital innovation (Bunduchi et al., 2022). As critical actors of entrepreneurial firms, owners, play a crucial role in product innovation (Mathias and Williams 2017; Zuzul and Tripsas 2020). Cognitive frames - interpretative schemes to assign meaning and make sense of the world - (Cornelissen and Werner, 2014) are used to understand how enterprises manage innovation. Raffaelli et al. (2019) proposed the top management team's cognitive capability as a crucial factor affecting innovation adoption. The managerial cognition as the driver of change in firms' digitalization capabilities is studied in Tripsas and Gavetti (2000).

Therefore, personal characteristics are expected to significantly influence the invention process.

The individual characteristics of key people involved in the invention process, especially inventors, significantly increase efficiency and effectiveness in patent production. The variables investigated are personal initiative, leadership, and intrinsic motivation (Denti and Hemlin 2015), personal network, risk aversion, information network, and labor market insurance (Faleye et al. 2014), gender, belonging to minorities (Link & van Hasselt 2020), expatriate status (Goel and Göktepe-Hultén 2021), educational and professional background. Interestingly, analyzes how chief operating officers' (COOs') characteristics affect exploration via patenting and venturing. The COOs' demographic and professional characteristics analysis shows that longer careers negatively impact patenting while positively venturing. Likewise, gender affects differently, as female COOs relate to venturing, but no relation is detected about patenting. COOs' professional experience in development is linked to patents but not venturing.

Some works have investigated the role of individual and professional characteristics in the specific context of university patenting and technology transfer activities (Baldini 2011; Bercovitz and Feldman 2007; Boardman and Ponomariov 2009), whereas they deepened the faculty motivations to patent (prestige, reputation, knowledge exchange, incentives), level of personal commitments toward technology transfer, funding sources, institutional affiliations, tenure status, support of students, scientific values, and demographic attributes.

Many works have addressed the topic of women in innovation and entrepreneurship (Cunningham et al. 2017; Goel et al. 2015; Leahey and Blume 2017; Link 2017). A contribution to the impact of age and gender on digital capabilities, namely, on selfie-related behaviors, was proposed by Dhir et al. (2016).

Expatriate researchers' impact on innovation productivity is an essential issue in terms of the policy. Investigating the productivity of foreign researchers and international scientific mobility is important (OECD 2001; Teichler 2015; van der Wende 2015; Ardito et al., 2021; Lenzi, 2009), especially regarding return mobility and the productivity of researchers coming back to their own countries (Baruffaldi and Landoni 2012; Gibson and McKenzie 2014; Jonkers and Tijssen 2008). Ardito et al. (2021) detected a higher rate of general-purpose innovations in teams including foreign members. Ostrovsky and Picot (2021) investigated the attitude to creating immigrant-owned firms in Canada, finding that immigrant-owned SMEs were somewhat more likely to innovate.

As for ethnic diversity and the presence of minorities, they seem to boost the dynamic capabilities of a company and its innovativeness.

Other studies focused on the role of scientific knowledge within teams for the development of technological innovation (Ardito et al., 2021), the institutional ownership, and the level of innovation measured by the number of patents and patent citations (Sakaki and Jory, 2019), on the ability of inventor CEOs for innovation (Lin et al., 2021). Namely, Lin et al. (2021) investigate the role of inventor CEOs within firms' innovation process. Surprisingly, CEOs' general ability is associated with higher innovation outcomes, while their managerial ability lowers innovation results (Lin et al., 2021). On the contrary, Ardito et al. (2021) focus on the team-level composition of scientific and educational backgrounds as well as team internationalization: they found that higher scientifical and academic levels in the team reduce the likelihood of patenting general-purpose solutions, while a higher team internationalization brings more technologies applicable to different domains (Ardito et al., 2021). However, ownership composition has also been investigated under the public vs private ownership perspective (Sakaki and Jory, 2019): institutional investors adopt a long-term view and bring a sense of ownership stability that benefits firms' innovation.

As a general result, Su and Moaniba (2020) argue that individuals, firms, and countries play a distinctive and moderating role in a collaborated patenting activity, thus, highlighting how individuals' characteristics impact R&D collaboration network success (Su and Moaniba, 2020).

Overall, few studies analyze the impact of the human factor at the top management level and the invention process's output, in particular, measured through the production in terms of patents. Even fewer studies exist concerning digital innovation.

From an overall point of view, we can say that the topic related to the impact of owners' characteristics on innovation in the context of Industry 4.0 is a new and promising research field.

More specifically, this article aims to investigate the impact of owners' individual characteristics on the invention process by analyzing the output in terms of patents.

2.3. Model and hypotheses

The research model has based on the hypothesis that owners' characteristics influence the digital innovation output, whose proxy is the number of granted patents. In the following, the single hypotheses formulated are described.

Results related to the influence of gender on the propensity to innovation and patenting are not unique. Link and van Hasselt (2020) studied the effect of owners' gender on patenting disposition: women-owned firms are associated with fewer patent applications than men-

owned ones. Some studies found no significant gender differences in innovation productivity (Goel and Göktepe-Hultén, 2021).

Other studies found that females are more likely to promote exploration via patenting (). Female leaders often demonstrate cooperative and collaborative leadership styles nurturing a greater innovation propensity (Dezso and Ross, 2012). Females can provide more creativity and flexibility than males, allowing innovation activity to be better explored (Østergaard et al., 2011; Ruiz-Jimenez et al., 2016). Innovativeness can benefit from the creativity and different views coming from gender diversity (Dezso and Ross, 2012). Females can stimulate enthusiasm and curiosity, bringing exceptional views and experiences encouraging to challenge the status quo via patenting (Marcel, 2009). Evidence suggests that female leadership results in higher firm innovativeness (Ruiz-Jimenez et al., 2016), and managerial gender heterogeneity fosters firm innovation efforts (Hoobler et al., 2018).

Therefore, we propose the following hypothesis:

H1: gender heterogeneity positively influences the number of granted patents.

Empirical evidence on expatriate researchers and innovation is not so many (Corley and Sabharwal 2007; Levin and Stephan 1999), but essential research has deepened the topic (Teichler 2015; van der Wende 2015).

Findings demonstrate general accordance with expatriate researchers' positive impact on innovation productivity. In the U.S., Levin and Stephan (1999) showed that foreign-born and foreign-educated scientists provided high contributions; Corley and Sabharwal (2007) showed that foreign-born scientists were more productive than home country-born scientists.

Internationally mobile researchers can bring different perspectives promoting and facilitating innovation and are often more productive by refining and re-combining novel and existing knowledge to generate innovation (Teichler, 2015).

Many countries have promoted programs to attract international talents, contaminate their own national competencies, and create new networks benefitting the local research community.

Therefore, we propose:

H2: heterogeneity in terms of expatriation conditions positively influences the number of granted patents.

Research on the impact of ethnicity on innovation is relatively poor. Link and van Hasselt (2020) explored the effect of owners' ethnicity on the patenting attitude proving that minority-owned firms show a higher patenting propensity.

In the U.S., the Small business innovation research (SBIR) and Small Business technology transfer (SBTT) programs encourage the participation of minorities in technological innovation (National Academies of Sciences, Engineering and Medicine, 2015), as it improves science and technological innovation.

Ethnic diversity improves the dynamic capabilities (Fleming, 2001; Jones, 2008; Katz and Martin, 1997), which in turn increases the performance of firms related to innovation. Ethnic and education diversity in the workforce is positively correlated with the intensity of radical innovation (Mohammadi et al., 2017), suggesting that great ethnic diversity in the workforce significantly improves innovativeness. Moreover, while more external links could replace other kinds of variety like the disciplinary-one, ethnic diversity could not.

Therefore, we propose:

H3: The presence of minorities among owners positively influences the number of granted patents.

Some studies found that the functional background of CEOs is associated with leaders' attitudes toward change (Musteen et al., 2006). Liu et al. (2018) demonstrated that leaders' features, including professional background, influence firm performance. The development experience of CEOs is associated with greater exploration and change efforts (Barker and Mueller, 2002). Leadership style depends in many cases on occasion: a professional background in output-related functions like R&D fosters growth strategies and sustains innovation expenses so, pursuing organic growth through innovation; furthermore, a manager whose cognitive base includes R&D is more likely to foster a firm's technological innovation via patenting (Chakravarty and Grewal, 2016).

Therefore, we propose:

H4: The level of education of owners positively influences the number of granted patents.

In the model, we also consider control variables related to the firm's size and financial dimension: number of employees, operating turnover, ROE - Return on Equity, and net income.

3. Methodology

This paper performs a Multiple Linear Regression analysis with SPSS 27.0, empowered with ad hoc coding to verify the four Gauss–Markov assumptions: (A1) standard error means equal to zero; (A2) homogeneity; (A3) homoskedasticity; (A4) covariances of mistakes similar to zero (Aiken and West, 1991; Baron and Kenny, 1986; Cohen et al., 2003; Hayes and Cai, 2007; Hayes and Matthes, 2009; Poole and O'Farrell, 1971; Wooldridge, 2010).

The sample selection process followed the recent literature on patenting firms (Giglio, 2021; Giglio et al., 2021). In detail, the single-random sampling without replacement includes firms – as the sampling unit – that patented innovations about the keyword "Industry 4.0", identified through a text-based search. To avoid that a single-keyword search could introduce any bias in the sampling criteria, the selection process also covered the WIPO categories closer to the Industry 4.0-based patents, such as audio-visual technology, telecommunications, digital communication, basic communication processes, and I.T. methods for management. The data about the five WIPO categories were pooled together to generate a larger sample, based on Maliatsina and Kimpimäki (2020). Following Ostrovsky and Picot (2021), we adopted the pooling method, as research hypotheses and variables are shared among the 5 sub-sets. The final dataset includes firms' size and financial performances, ownership team composition and education, and patenting activity. The patenting period is considered a 5-year timeframe to control for the elasticity of patenting R&D departments (Ahuja and Katila, 2001; Giglio et al., 2021; Hall, Jaffe, and Trajtenberg, 1999; Hausman and Griliches, 1984; Jaffe and Trajtenberg, 1996; Johnson, 2002) – i.e., firms were selected only if they had at least one granted patent between 01/01/2016 and 31/12/2020.

BVD database has been chosen because it merges and harmonizes ready-to-use data from different patent databases globally. Hence, preliminary methodological steps are mostly unnecessary to standardize and cleanse data and derive metrics (Kim and Lee, 2019) (Giglio, 2021).

Although there is no universally shared time interval in literature for patent-related analyses, we rely on the 5-year elasticity of patenting for R&D departments (Ahuja and Katila, 2001; Giglio et al., 2021; Hall, Jaffe, and Trajtenberg, 1999; Hausman and Griliches, 1984; Jaffe and Trajtenberg, 1996; Johnson, 2002).

This study considers the following control variables: number of employees (SIZE), return on equity (ROE), operating turnover (TURN), and net Income (Inc) as a proxy for a firm's size and financial performances. Such firm-level dimensions have been controlled through the variables available in the dataset, following previous research (Xu and Wang, 1999; Sun et al., 2002; Choi et al., 2011). Firm size was selected based on consolidated studies involving patents and the total amount of employees (Francois and Belarouci, 2022; Micozzi et al., 2021; Mátyás et al., 2019; Matricano, 2020); ROE was selected due to its widely investigated relationships with patenting activity (Li and Di, 2021; Jin et al., 2020; Chiu et al., 2020; Nunes et al., 2018; Patel and Ward, 2011; Coombs and Bierly, 2006); likewise, turnover was selected due to proven relationships between firm performance and patents (Paula and Silva Rocha, 2021; Matricano, 2020); finally, Income has been selected due to its established links to patenting activity (Burrus et al. 2018; Wesseling et al., 2015; Lee, 2010; Sood and Dubois, 1995; Chakrabarthi and Halperin, 1990).

Independent variables related to the ownership team are gender heterogeneity (GEND), heterogeneity of expatriation conditions (EXP); the presence of minorities (MIN); level of education (EDU).

Finally, the dependent variable is the number of granted patents (PAT).

Table 1 summarizes the variables above.

Independent variables are operationalized as follows: GEND is equal to 1 when there are female owners in the company, 0 otherwise; EXP is equal to 1 if there are expats within the ownership team of a company headquartered in a particular country, 0 otherwise; MIN is equal to 1 when there are owners from the same country of the firm, but belonging to minorities, 0 otherwise; EDU is equal to 1 if owners have at least a degree, 0 otherwise.

Tables 2–5 show the frequency of independent variables (GEND, EXP, MIN, EDU).

The overall sample includes 553 observations (1 missing value). There is an overall balance in gender heterogeneity, while only one-fourth of the total sample includes expats. 2.5 % of firms in the sample have owners from minority groups, and 13.2 % have degree-level education.

4. Results

No variables are removed from the multiple linear regression analysis. Hence, no perfect multicollinearity is detected. Fit indices are acceptable: $R^2 = 0.531$, Adj $R^2 = 0.524$. Therefore, the model explains more than 50 % of the variability of the dependent variable, far beyond the minimum threshold of 0.20 for cross-sectional data. The regression test ($F = 76.540$, p-value $= 0.000$) confirms the overall significance of the model (Tables 6, 7). Among the control variables, SIZE and TURN positively and significantly impact the dependent variable. However, TURN has an illusory significance, as the corresponding confidence interval is a neighborhood of zero. Only SIZE exerts an influence on granted patents, coherently with literature (Giglio, 2021). GEND, MIN, and EDU significantly and positively impact PAT.

The assumptions of the linear regression models were fulfilled (Poole and O'Farrell, 1971). Gauss–Markov assumptions have been tested through diagnostic tools as follows. Multicollinearity has been tested by checking: correlations among independent and control variables, condition indices, and variance inflation factors (VIFs). Tables 7–9 show that correlations (below 0.5), VIFs (below 1.6), and condition indices (below 3.7) confirm that no relevant multicollinearity is detected (Cohen et al., 2003; Hayes and Matthes, 2009; Miceli et al., 2014). Endogeneity has been controlled by excluding conceptual mistakes (e.g., reverse causality), using control variables, and grounding the research hypotheses in consolidated literature results (Wooldridge, 2010). Autocorrelation has been avoided by definition in cross-sectional datasets (Loglisci and Malerba, 2017). Heteroskedasticity has been tested through scatter plot of standardized residuals vs dependent variable, White tests I and II (only squared predictors, and squared predictors and interaction terms, respectively), Breusch-Pagan test, and Newey-West estimation of robust standard errors (with HC3 estimator): no heteroskedasticity is detected - p-value > 0.05 - (Aiken and West, 1991; Baron and Kenny, 1986; Brambor et al., 2006; Echambadi and Hess, 2007; Hayes and Cai, 2007; Kaspar and Fuchs, 2021).

So considering the hypotheses formulated in the previous section, we can summarize the results as follows:

- H1, H3, and H4 are accepted; H2 is rejected.
- Regarding the control variables, SIZE and TURN positively impact the dependent variable, even if TURN has a zero confidence interval. Both SIZE (number of employees) and TURN (operating turnover) are necessary proxies of the firm dimension, confirming that innovation and patent activity are more developed in large companies than in small ones.

5. Discussion

This study focuses on the role that the personal characteristics of business owners play in digital innovation processes in terms of their patenting activity. Namely, we identified some relationships among firms' granted patents and firms' diverse ownership composition in terms of gender, team internationalization, and education level that contribute to the understanding of how owners' characteristics and ownership team composition affect innovation output in terms of

Table 1
Variables utilized.

Independent and control variables	Dependent variable
Independent variables	Number of granted patents
Heterogeneous gender composition	
Heterogeneous expatriation conditions	
Existence of minorities among owners	
Level of education of owners	
Control variables	
Number of employees	
Return on equity	
Operating turnover	
Net income	

Table 2
Frequency of GEND.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	289	52.3	52.4	52.4
	1	263	47.6	47.6	100.0
	Total	552	99.8	100.0	
Missing	System	1	0.2		
Total		553	100.0		

Table 3
Frequency of EXP.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	414	74.9	75.0	75.0
	1	138	25.0	25.0	100.0
	Total	552	99.8	100.0	
Missing	System	1	0.2		
Total		553	100.0		

Table 4
Frequency of MIN.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	538	97.3	97.5	97.5
	1	14	2.5	2.5	100.0
	Total	552	99.8	100.0	
Missing	System	1	0.2		
Total		553	100.0		

Table 5
Frequency of EDU.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	479	86.6	86.8	86.8
	1	73	13.2	13.2	100.0
	Total	552	99.8	100.0	
Missing	System	1	0.2		
Total		553	100.0		

Table 6
Results of the regression test.

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	298404314810.367	8	37300539351.296	76.540	.000[b]
	Residual	263647207769.719	541	487333101.238		
_	Total	562051522580.086	549			

Table 7
Regression parameters and Variance Inflation Factors.

Model		Unstandardized Coefficients		Sig.	Collinearity Statistics
		B	Std. Error		VIF
1	(Constant)	−2666.946	1383.819	0.054	
	SIZE	0.356	0.029	0.000**	1.386
	GEND	5333.011	3161.982	0.093*	1.022
	EXP	3488.164	2722.485	0.201	1.572
	MIN	37817.989	6551.544	0.000**	1.202
	EDU	12891.230	3423.265	0.000**	1.522
	ROE	0.353	25.372	0.989	1.020
	TURN	0.000	0.000	0.000**	1.520
	Inc	-0.001	0.001	0.362	1.279

*Significance level: $p < 0.1$.
**Significance level: $p < 0.001$.

granted patents related to digital innovation and, namely, Industry 4.0. We believe that the role of owners is particularly relevant in digital innovation, whereas innovation processes are less structured and affected by stimuli from subjects with power (Bartoloni et al., 2021). Moreover, actual results from literature show that digital innovation has some peculiarities compared with non-digital creation (Nylund and Brem 2021). Therefore, such exceptions need to be investigated with ad hoc studies, as the generalization of results about non-digital innovations does not apply to digital innovations (Nylund and Brem 2021). While numerous studies focus on the impact of the personal characteristics of inventors (e.g., Biga-Diambeidou et al. 2021; Teruel & Segarra-Blasco 2021) and diversity in the individual elements of the governance team on innovation in general (e.g., Ain et al. 2021; Cumming and Leung 2021; Konadu et al. 2022), to the best of our knowledge, this is the first work that considers the personal characteristics of owners about digital innovation. Hence, following recent studies (Annarelli et al. 2021; Elia et al. 2021; Del Giudice et al. 2021), the theoretical contribution of our work aims at filling in the gap in the literature about a more comprehensive understanding of enabling factors (including personal ones) related to digital innovation and, namely to Industry 4.0, to explore and identify possible determinants of firms' patenting activity. Factors like gender (Dezso and Ross, 2012), education level, and expatriate status (Liu et al., 2018; Barker and Mueller, 2002; Ardito et al., 2021) are much debated in the literature and were considered in this study. As for education level, we assume that higher education and capabilities (e.g., managerial or general ones) of the owners make them more inclined and capable of supporting innovation (Barker and Mueller, 2002), but there is a mitigating effect of the type of education or capability on the actual innovation output, thus, making the existing literature not entirely conclusive on educational factors (Lin et al. 2021). Hence, we contribute to the ongoing discourse on how education impacts innovation output. As for gender and expatriate status, we considered the diversity of the ownership team. The primary hypothesis is that the interaction between individuals concerning these characteristics can favor the contamination, mutual motivation, and learning that guide digital innovation (Ardito et al., 2021). While several studies addressed the relationship between gender and innovation performance at large (Link and van Hasselt 2020; Ain et al. 2021; Biga-Diambeidou et al. 2021; Cumming & Leung 2021; Teruel and Segarra-Blasco 2021; Kamberidou 2020; Østergaard et al., 2011; Ruiz-Jimenez et al., 2016; Dezso and Ross, 2012; Marcel, 2009), literature does not provide fully

Table 8
Correlations.

Pearson Correlations	SIZE	GEND	EXP	MIN	EDU	ROE	TURN	Inc
SIZE	1.000	0.107	0.169	0.261	0.341	0.020	0.458	0.289
GEND	0.107	1.000	0.414	0.077	0.303	-0.013	0.137	0.046
EXP	0.169	0.414	1.000	0.279	0.478	0.070	0.184	0.068
MIN	0.261	0.077	0.279	1.000	0.107	0.004	0.247	0.211
EDU	0.341	0.303	0.478	0.107	1.000	0.049	0.335	0.190
ROE	0.020	-0.013	0.070	0.004	0.049	1.000	0.006	0.097
TURN	0.458	0.137	0.184	0.247	0.335	0.006	1.000	0.430
Inc	0.289	0.046	0.068	0.211	0.190	0.097	0.430	1.000

Correlations among independent and control variables are not significant; no multicollinearity is detected.

Table 9
Collinearity diagnostics.

Dimension	Eigenvalue	Condition Index	Variance Proportions								
			(Constant)	SIZE	GEND	EXP	MIN	EDU	ROE	TURN	Inc
1	3.645	1.000	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.01
2	1.242	1.713	0.04	0.04	0.05	0.03	0.08	0.00	0.05	0.08	0.13
3	0.954	1.954	0.00	0.00	0.01	0.04	0.05	0.03	0.62	0.00	0.10
4	0.843	2.080	0.00	0.02	0.00	0.02	0.66	0.05	0.10	0.04	0.02
5	0.678	2.319	0.18	0.00	0.08	0.04	0.00	0.35	0.14	0.00	0.04
6	0.602	2.461	0.01	0.48	0.01	0.05	0.00	0.02	0.03	0.01	0.46
7	0.436	2.891	0.00	0.28	0.00	0.00	0.00	0.03	0.02	0.85	0.21
8	0.325	3.350	0.12	0.13	0.01	0.69	0.19	0.50	0.00	0.00	0.02
9	0.276	3.635	0.63	0.02	0.83	0.10	0.00	0.00	0.04	0.00	0.00

shared results, and the case of digital innovation is hitherto under-investigated. Therefore, our research contribution sheds more light on the impact of gender diversity on patenting activity in digital domains, namely Industry 4.0. Finally, team internationalization, that is, ethnicity and nationality diversities, according to Ardito et al. (2021), is linked to higher innovation performance in many areas (see also: Fleming 2001; Mohammadi et al. 2017; Krabel et al. 2012; Mathieu et al. 2013; Teichler 2015; van der Wende 2015; Alnuaimi et al. 2012, Tzabbar and Vestal 2015; Mulkay 1974), but there is an apparent lack of deeper investigation and consolidated results, as pointed out by Link and van Hasselt (2020). Thus, our work aims to fill in such a gap in literature by tackling nationality diversity in terms of expats and ethnic minorities.

The results confirm that individual factors like the education level and diversity of the ownership team favor greater productivity and impact in terms of patenting in the digital innovation domain.

As for education level, the result is not entirely intuitive as the owners are not directly involved in the innovation process. However, our results are consistent with the literature that argues that top management roles that exercise power over the organization push innovation processes when their education level is higher and their technical competence grows (Barker and Mueller, 2002). Coherently with mainstream literature, but in contrast with Lin et al. (2021), our findings do not link innovation performance to specific managerial abilities.

As for minority groups, findings are aligned with previous research (Ardito et al., 2021; Fleming, 2001; Mohammadi et al., 2017), but our contribution sheds more light on different types of minority groups and team internationalization, as requested by Link and van Hasselt (2020). In particular, we checked separately for ethnic minority and national diversity within ownership teams, finding that only ethnicity is a significant factor in digital innovation performance. Such diversity conditions have been termed 'team internationalization' (Ardito et al., 2021). Indeed, minority owners can often be considered intellectual migrants (Mulkay 1974) and highly motivated individuals with diverse life experiences exposing them to diverse knowledge and an international network of personal contacts (e.g., Krabel et al., 2012; Mathieu et al., 2013; Teichler 2015; van der Wende 2015). Therefore, international owners' teams facilitate access to knowledge. Complementary resources (e.g., laboratories, scientific partnerships) are needed to carry out digital innovation processes. Diverse groups, besides, are often characterized by the facility of knowledge spillovers which help make sense of the rapidly evolving digital technologies (e.g., Alnuaimi et al., 2012), as well as by a tolerant and open climate that facilitates risk-taking and, in general, the invention process (Tzabbar & Vestal, 2015).

Past studies investigated whether women in top positions within organizations impact firms' innovation measured by patent applications, mainly finding positive evidence (Dezso and Ross, 2012), with some exceptions and conditional constraints (Teruel and Segarra-Blasco, 2021). Gender diversity has been found to affect innovation performance positively (e.g., Link and van Hasselt 2020; Ain et al. 2021; Biga-Diambeidou et al. 2021; Cumming & Leung 2021), even if, in some cases, results are mixed, as in the case of Teruel and Segarra-Blasco (2021) who found a positive relation only in the case of teams that are also occupationally diverse. Our paper extends this research stream to the much less investigated case of digital innovation (Kamberidou 2020), finding a significant and positive relationship between gender diversity and innovation output. The presence of female individuals in power groups favors creativity and flexibility, fostering digital innovation (Østergaard et al., 2011; Ruiz-Jimenez et al., 2016) and diversity of points of view (Dezso and Ross, 2012). Female owners can bring the owners' team the enthusiasm and curiosity (Marcel, 2009) necessary in a dynamic domain such as Industry 4.0. Our findings align with mainstream literature, confirming a positive impact of gender diversity on innovation output, not linked to other diversity conditions (Teruel and Segarra-Blasco 2021).

The original contributions to understanding gender, ethnicity, and education diversity are based on hypotheses grounded in studies on non-owners and non-digital innovations: further research should take our work as a starting point to further deepen the links between personal characteristics and patenting intensity. As such, new dimensions and variables should be selected and investigated, like the environmental context (e.g., country patent stock) or firm's path dependency in innovation patenting (e.g., application experience, patenting intensity over time) as well as technology-level variables (e.g., technology age).

6. Conclusions

Even though digital innovation can vigorously accelerate society's transformation due to its pervasive impact, the topic is still poorly studied (Annarelli et al., 2021). This is also true when considering digital innovation in Industry 4.0. Understanding and stimulating the enabling factors of digital innovation is an important issue (Elia et al. 2021; Del Giudice et al. 2021).

Enabling factors can be identified at the organizational, environmental, and individual levels. Within these levels, the personal dimension is probably the least studied. There exist studies on the role of top managers (Firk et al. 2021), key people involved in the innovation process, and employees or managers in functions like Operations or R&D (Goel & Göktepe-Hultén, 2021; Link & van Hasselt, 2020). Studies focused on business owners are rare, even if the impact on business performance is expected to be high, especially in Industry 4.0, where processes are less structured, so top levels are requested to pursue an entrepreneurial attitude (Bartoloni et al., 2021).

This paper aims to fill this gap. An empirical analysis was carried out on data gathered from the BVD database related to a sample of over 550 firms headquartered worldwide engaged in digital innovation.

The paper aimed at answering the research question stated in the introduction, i.e., what individual characteristics of owners have a significant impact on digital innovation output, declined in the four specific hypotheses. Three out of four hypotheses were entirely accepted, demonstrating that the gender diversity, the presence of minorities in owners, and the level of education of owners significantly impact patenting activity in digital innovation. Considering the control variables, the company size influences the attitude to innovation and patenting.

The research has substantial practical implications. The positive impact of specific individual characteristics on the innovation performance can encourage companies to include in the teams people having the factors identified and stimulate initiatives or programs by policymakers.

For instance, many countries have already developed policies and programs to involve people with different characteristics in innovation activities. One of the aims of the American Small business innovation research (SBIR) and Small Business technology transfer (STTR) programs is to encourage the participation of different people in technological innovation. Already in 2013, some initiatives focused on the involvement of women, minorities, and other categories in the SBIR and STTR programs (National Academies of Sciences, Engineering, and Medicine, 2015) to expand the pool of SBIR/STTR-funded researchers and identify mechanisms for improving participation rates: such categories helped improving science and technological innovation, indeed.

This paper provides preliminary empirical evidence that is not exempt from limitations that may identify future research directions. One end is intrinsically related to the research focused on owners' characteristics that have never been studied in terms of impact on digital innovation. While there are studies on other people involved in the digital innovation process, this is one of the first works that consider the effects of individual characteristics of owners. So, our hypotheses primarily rely on existing studies.

Future research in this area should consider other variables related to the external context, such as the country's patent stock or related to the specific application experience of the company. The temporal dimension of patenting, understood as the patenting intensity over time, could be significant: it is reasonable to retain that the patenting activity in a

certain period will influence the patenting performance of future periods. Other variables to be considered are specifically related to the characteristics of the innovation, for example, the technology age. Also, ownership concentration and ownership stake could be relevant variables to include in future studies, as well as female members' stake, owners' founding role, and owners' involvement in operational management. In adding new variables, additional mediating/moderating effects could be tested. In this context, another area subject to further research is the definition of the control variables: the number of employees and the operating turnover can be considered as the correct proxy for describing the company size, while others (e.g., R&D expenses or R&D%) should be considered as related to financial performance.

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CRediT authorship contribution statement

Vincenzo Corvello: Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Jaroslav Belas:** Writing – review & editing, Writing – original draft, Validation. **Carlo Giglio:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Gianpaolo Iazzolino:** Writing – review & editing, Writing – original draft, Validation, Conceptualization. **Ciro Troise:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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