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Jordana Rech Graciano dos Santos, Valentina Meliciani, Marco Pini, Roberto Urbani

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Beyond borders: assessing the impact of digital and green innovation on firms' export capabilities

Jordana Rech Graciano dos Santos, Luiss Guido Carli University, jrech@luiss.it
Valentina Meliciani, Luiss Guido Carli University, vmeliciani@luiss.it
Marco Pini, Centro Studi delle Camere di Commercio Guglielmo Tagliacarne, marco.pini@tagliacarne.it
Roberto Urbani, Luiss Guido Carli University, rurbani@luiss.it

Abstract

This paper examines the relationship between digital and green innovation and the internationalization of Italian firms. Relying on survey data from a sample of 2,500 Italian manufacturing firms in 2023, this research examines the role of these innovations in enhancing firms' ability to export and expand their export volumes. We find that the effect on export capabilities rises under two conditions: investing in a large number of technologies (digital intensity) and complementing fixed capital formation with training activities. Importantly, the combined effect (i.e., digital and green innovation) amplifies firms' export performance, underscoring the significance of integrating technological and sustainable strategies in firms' internationalization efforts. These insights have managerial implications for the best business strategy to adopt within the firms and policy implications highlighting the importance of simultaneously supporting digital and green innovation initiatives.

Keywords: internationalization; digital innovation; green innovation; twin transition; export behavior
JEL: O33; Q55; F14; L25; F23

1. Introduction

In an era marked by rapid technological advancements and increasing environmental awareness, the convergence of innovation and internationalization has become a critical frontier in the field of strategic management. As firms seek to expand their global presence, adopting digital and green innovations emerges as a transformative force, redefining competitive landscapes and reshaping how firms engage with international markets (Carboni and Medda, 2020).

Although the connection between innovation and market competitiveness is evident (Cefis et al., 2023; Soete, 1981; Dosi at al. 1990; Laursen and Meliciani, 2000; 2002; 2010; Altomonte et al., 2013; Dosi et al. 2015; Braga et al., 2018), the role of digital and green technologies for international trade, especially at the firm level and taking into account both types of innovation, remain underexplored.

The integration of digital and green strategies—often referred to as the 'twin transition' (Montresor & Vezzani, 2023)—is particularly promising yet poorly understood, requiring for a detailed examination of how these synergies can be leveraged to enhance firms' internationalization efforts.

Specifically, the research literature lacks comprehensive insights into how these twin innovations interact to influence not just the initiation of export activities but also the expansion of export volumes among established international traders. This study aims to fill this gap by examining whether and how the combined application of digital and green innovations can serve as a dual enabler for both entering new international markets and increasing export volumes. The research question guiding this paper is: How do digital and green innovations, separately and together, correlate with the ability of firms to start exporting and to increase their export volumes? This question aims to assess the potential of these innovations as strategic tools for competitive positioning and market engagement on a global scale.

This paper makes several contributions to the fields of strategic management and innovation. First, it addresses a crucial gap by empirically investigating the specific roles of digital and green innovations in enhancing the export activities of manufacturing firms. This is particularly relevant as the relationship of these

innovations with international market dynamics is underexplored, especially within the Italian manufacturing context.

Second, the study demonstrates how digital and green innovations not only accompany a firm's entry into international markets but also support the expansion of export volumes.

Third, by highlighting the advantages of integrating digital and green innovations, the research enriches theoretical debates about the interaction between different types of innovation and their combined impact on export performance.

2. Literature review and research hypotheses

The adoption of digital technologies and the transformation of business processes, models, and ecosystems, collectively referred to as digital innovation, has been identified as a key facilitator of international trade (Autio et al., 2018).

The extant literature underscores how digital technologies enable firms to overcome traditional barriers to entry into foreign markets, enrich their market intelligence, streamline operations, and offer innovative products and services tailored to diverse market needs (Luo et al., 2016). Digital innovation not only optimizes a firm's internal processes but also amplifies its market reach and customer engagement strategies, thus boosting export performance and redefining how companies create, deliver, and capture value (Du et al., 2024; Kotabe et al., 2017). In line with this literature, we formulate our first hypothesis:

Hypothesis 1 (H1): Digital innovation is positively associated with firms' export capabilities in terms of probability of exporting and achieving export growth.

The concept of digital innovation encompasses not only the creation of new digital technologies but also the initiation, development, implementation, and exploitation of these technologies (Cooper and Zmud, 1990). The coevolution between digital technologies, innovation, and skills is a source of firms' competitive advantage. Even minor alterations that initially appear inconsequential can, in fact, lead to profound and often unanticipated transformations, particularly in how to adopt these and integrate to the reality these digital technologies. For example, the capacity to codify human tasks into software significantly impacts the skills

needed and the types of jobs available (e.g., Helper et al., 2019). This shift is driving changes in skill requirements both within and across organizations, industries, and countries, rendering many existing skills redundant or obsolete (Autor, 2015; Autor et al., 2015; Ciarli et al. 2021).

Technological skills can improve the adaptability and flexibility of the local knowledge base and workforce, not only by increasing efficiency in gathering, organizing, and interpreting information, but also by enhancing traditional skills to better support research, communication, planning, and organization (Santoalha et al., 2021). This is shown in the results of the study by Cirillo et al. (2023), which demonstrates that industrial policies promoting digitization should prioritize not only asset acquisition but also upskilling, training, and the institutional development of digital competencies. Such a combined approach is important since investment in the technologies alone might be ineffective due to the lack of trained employees with the necessary digital skills.

We therefore test the following hypothesis:

H2: *The combination of digital innovation and employee training is positively associated with firms' export capabilities in terms of probability of exporting and achieving export growth*

In addition to digital innovation, green innovation serves as a vital mechanism for the creation and implementation of environmentally conscious products, processes, and business practices, which can serve as a crucial environmental management strategy (Schrank and Kijkasiwat, 2024). Moreover, it is a strategy that international partners use to evaluate companies as responsible and trustworthy, which can lead to export opportunities (Boso et al., 2013).

Green technology innovation includes two main strategies: green product innovation and green process innovation (Salvadó et al., 2012). Green product innovation focuses on designing products using non-toxic materials or biodegradable components to reduce environmental impact and improve energy efficiency (Lin et al., 2013; Kivimaa & Kautto, 2010). In parallel, green process innovation aims to optimize production processes by reducing energy and resource consumption, minimizing emissions, and transitioning to sustainable energy sources (Salvadó et al., 2012; Kivimaa & Kautto, 2010).

Regarding the role of product innovation in enhancing export capabilities, previous research emphasizes the significance of breakthrough innovations, which arise from a cycle of learning and knowledge accumulation, enabling firms to develop groundbreaking products and gain competitive advantages (Clausen and Pohjola, 2013). Additionally, green process innovation supports firms in producing environmentally sustainable products by improving product quality, expanding product variety, and enabling the creation of entirely new products, thereby enhancing market share and competitive positioning (Kam-Sing Wong, 2012; Bigliardi and Ivo Dormio, 2009; Damanpour, 2010). Thus, environmentally sustainable innovations respond to the growing global demand for green solutions, giving companies a competitive advantage by improving their appeal in the international market.

In view of these possible channels, we test the following hypothesis:

H3: Green innovation is positively associated with firms' export capabilities in terms of probability of exporting and achieving export growth

Recently the literature has started reflecting upon the complementarity between digital and green innovation. The green and digital transitions are thus interrelated, and so intrinsically linked to be considered as "twin transitions" (EC, 2020). According to the Science for Policy report by the Joint Research Centre (JRC), the green and digital transitions can reinforce each other, where digital technologies can be key enablers for reaching the European Green Deal objectives. Digital innovations not only open new export markets but also establish firms as leaders in sustainability (Montresor and Vezzani, 2023) and technological advancement. The incorporation of digital and green innovation strategies can significantly enhance firms' international competitiveness, providing a distinctive competitive advantage in global markets (Sun and He, 2023; Huang and Chen, 2022; Feng et al., 2022). We assume that when firms simultaneously integrate digital technologies and green practices, they leverage the complementary strengths of both to improve operational efficiency and meet the rising global demand for sustainable and technologically advanced products. This integrated approach is expected to significantly enhance firms' abilities to penetrate and succeed in international markets. We, therefore, test the following hypothesis:

H4: The combination of digital and green innovations is positively associated with firms' export capabilities in terms of probability of exporting and achieving export growth

3. Data and empirical strategy

3.1 Data

The data come from a special survey conducted by the Centro Studi Tagliacarne-Unioncamere (Italian Union of Chambers of Commerce) at the beginning of 2023 on a sample of around 2,500 Italian manufacturing companies with 5 and 499 employees. This fresh data allows us to analyze the current strategic business investments and the export performance, including those expected.

The sample corresponds to 2.0 percent of the total Italian company population. The sampling procedure ensured the statistical representativeness of the data by considering both exhaustive and random sampling criteria. Three dimensions of firms were considered in the stratification: i) sector (nine economic activities of section C of the manufacturing industry of the Nace Rev. 2 classification); ii) size class in terms of employees (5-9, 10-49, 50-249, 250-499); iii) geographical location (North-West, North-East, Center, South). The survey was conducted using the CATI method (Computer-Assisted Telephone Interviewing) by a professional contractor to collect both qualitative and quantitative information about the company; several preliminary meetings were held with the contractor to explain to the interviewers the exact meaning of the questions, particularly in relation to the questions on investments in digital technologies and green innovation. The quality of the data was then validated.

3.2 Empirical strategy

As our dependent variable is binary, we use the probit model, which is the suitable econometric model for this case (Wooldridge, 2010, pp. 453-459). Thus, through probit regression, we model the conditional probability of exporting, as well as of registering an export growth, according to the different choices of investing in digital innovation and in green innovation. Specifically, our probit model is as follows:

$$\text{Prob}(Export = 1)_i = \Phi(\beta_0 + \beta_1 INNOV_i + \beta_2 C_i + \varepsilon_i)$$

where *Prob(Export=1)* represents the probability that the firm exports as well as the probability of registering an export growth. The variable *INNOV* is the main independent variable measuring the choice of investing in digital and in green innovation. *C* is a vector of control variables (for the description of all variables see Table 1, summary statistics are reported in Table 2). Table 1 displays the variables description, and Table 2 the summary statistics.

Collinearity problems do not emerge since all values of Variance Inflation Factor (Table 3) are below the critical value of 10 (Yoo et al., 2014). Φ is a standard normal cumulative distribution function. Finally, ε_i is the normally distributed random error with zero mean and constant variance $\mathrm{N}(0, \sigma^2)$ that captures any other unknown factors. To know the effects of any explanatory variable on the response probability $\mathrm{P}(Y = 1|\mathbf{x})$ we calculated the marginal effects (average marginal effects). Marginal effect indicates "the effect on conditional mean of Y of a change in one regressor, say, x_j" (Cameron and Trivedi, 2010, p. 343).

Table 1 – Variables description

Variables	Type	Description
Dependent variable		
EXP	Dummy	1 = if the firm exports; 0 = otherwise
EXP_GROWTH_23	Dummy	1 = if the firm has registered an export increase in 2023
EXP_GROWTH_24	Dummy	1 = if the firm expects an export increase in 2024
Main independent variables		
DIGITAL	Dummy	1 = if the firm has invested in 4.0 technologies in the period 2020-22; 0 = otherwise
DIGITAL INTENSITY	Categorical	0 = if the firm did not invested in the period 2020-22 in 4.0 technologies (*Digital_NO*); 1= if the firm invested in the period 2020-22 in only one 4.0 technology (*Digital_1*); 2= if the firm invested in the period 2020-22 in two 4.0 technologies (*Digital_2*); 3= if the firm invested in the period 2020-22 in three or over 4.0 technologies (*Digital_3over*)
DIGITAL&SKILLS	Categorical	0 = if the firm did not invested in the period 2020-22 in 4.0 technologies (*Digital_NO*); 1= if the firm invested in the period 2020-22 in only 4.0 technologies but not in skills training (*Digital_no_skills*); 2= if the firm invested in the period 2020-22 both in 4.0 technologies and skills training (*Digital_with_skills*)
GREEN	Dummy	1 = if the firm has invested in green innovation (eco-process and/or eco-product) in the period 2020-22; 0 = otherwise
GREEN TYPOLOGY	Categorical	0 = if the firm did not invested in the period 2020-22 in eco-process and/or eco-product (*Green_NO*); 1= if the firm invested in the period 2020-22 only in eco-product innovation (*Green_only_product*); 2= if the firm invested in the period 2020-22 only in eco-process innovation (*Green_only_process*); 2= if the firm invested in the period 2020-22 both in eco-product and in eco-process innovation (*Green_product&process*)
DIGITAL&GREEN	Categorical	0 = if the firm did not invested in the period 2020-22 in any innovation (*DG_NO*); 1= if the firm invested in the period 2020-22 only in digital innovation (*DG_only_digital*); 2= if the firm invested in the period 2020-22 only in green innovation (*DG_only_green*); 3= if the firm invested in the period 2020-22 both in digital and in green innovation (*D&G_both*)
Control variables		
Age	Discrete	Number of years since inception
Size	Dummies	1 = if the firm belongs to a n -size class; 0 = otherwise. The size class are the following: Small (5-49 employees); Medium (50-249 employees); Large (250-499 employees)
Geographical location	Dummies	1 = if the firm belongs to a n -geographical area; 0 = otherwise. The geographical areas are the following: North-West; North-East; Center; South
Sector	Dummies	1 = if the firm belongs to a n -sector; 0 = otherwise. The sectors are the following: Food products and beverages, Textiles, apparel, leather and related products, Wood and paper products, and printing, Chemicals, pharmaceuticals, rubber and plastics products, Non-metallic mineral products, Basic metals and fabricated metal products, Computer, electronic, optical products and electrical equipment, Machinery and transport equipment, Furniture and other manufacturing
Family	Dummy	1 = if the firm is family-owned; 0 = otherwise
Human capital	Continuous	Share of employees with tertiary degree (0-100)

Table 2 - Summary statistics

	Obs.	Mean	Std. Dev.	Min	Max
Dependent variables					
EXP	2,448	0.692	0.462	0	1
EXP_GROWTH_23	2,448	0.241	0.428	0	1
EXP_GROWTH_24	2,448	0.246	0.431	0	1
Main independent variables					
DIGITAL	2,448	0.543	0.498	0	1
Digital_1	2,448	0.271	0.445	0	1
Digital_2	2,448	0.147	0.355	0	1
Digital_3over	2,448	0.093	0.290	0	1
Digital_NO	2,448	0.457	0.498	0	1
Digital_no_skills	2,448	0.077	0.267	0	1
Digital_with_skills	2,448	0.466	0.499	0	1
GREEN	2,448	0.446	0.497	0	1
Green_NO	2,448	0.554	0.497	0	1
Green_only_process	2,448	0.320	0.467	0	1
Green_only_product	2,448	0.029	0.169	0	1
Green_product&process	2,448	0.097	0.296	0	1
DG_NO	2,448	0.324	0.468	0	1
DG_only_digital	2,448	0.230	0.421	0	1
DG_only_green	2,448	0.133	0.340	0	1
D&G_both	2,448	0.313	0.464	0	1
Control variables					
Age	2,448	33.798	16.543	3	136
Micro	2,448	0.215	0.411	0	1
Small	2,448	0.309	0.462	0	1
Medium-Large	2,448	0.476	0.500	0	1
North-West	2,448	0.355	0.478	0	1
North-East	2,448	0.330	0.470	0	1
Center	2,448	0.172	0.377	0	1
South	2,448	0.143	0.351	0	1
Food products and beverages	2,448	0.112	0.315	0	1
Textiles, apparel, leather and related products	2,448	0.116	0.321	0	1
Wood and paper products, and printing	2,448	0.107	0.310	0	1
Chemicals, pharmaceuticals, rubber and plastics products	2,448	0.108	0.311	0	1
Non-metallic mineral products	2,448	0.066	0.249	0	1
Basic metals and fabricated metal products	2,448	0.156	0.363	0	1
Computer, electronic, optical products and electrical equipment	2,448	0.078	0.268	0	1
Machinery and transport equipment	2,448	0.160	0.367	0	1
Furniture and other manufacturing	2,448	0.096	0.295	0	1
Family	2,448	0.738	0.440	0	1
Human Capital	2,448	10.730	11.070	0	83

Note: The sum of share of firms investing in digital innovation by number of technologies (*Digital_1, Digital_2, Digital_3more*) does not correspond to the total share of firms investing in digital technologies (*Digital*) because we took into account only the firms that stated the number of technologies (hence excluding from counting those that answered "Don't know").

Table 3 – Variance Inflation Factor (VIF)

	VIF
DIGITAL	1.12
Age	1.08
Medium	1.75
Large	2.27
North-East	1.32
Center	1.32
South	1.08
Textiles, apparel, leather and related products	1.87
Wood and paper products, and printing	1.83
Chemicals, pharmaceuticals, rubber and plastics products	1.82
Non-metallic mineral products	1.51
Basic metals and fabricated metal products	2.11
Computer, electronic, optical products and electrical equipment	1.61
Machinery and transport equipment	2.15
Furniture and other manufacturing	1.71
Family	1.15
Human Capital	1.19

The VIF is calculated after OLS regression.

4. Results and discussion

Tables 4-9 report the results. By controlling for several firms' structural characteristics (age, size, sector, location, governance, human capital), the results show that firms that have invested in Digital innovation (i.e., 4.0 technologies) are more likely to export than the others: marginal effect of the variable *DIGITAL* is positive and statistically significant (ME: 0.058; p<0.01, Table 4, Model A). Instead, with respect to export growth, digital innovation seems to show a less strong relationship: the marginal effects of Digital innovation related to the probability of increasing exports are not always statistically significant. Specifically, with reference to the export growth in 2023, the relationship is statistically significant but less than the case of the likelihood of exporting (p<0.05 vs p<0.01) and with a lower magnitude (0.038 vs 0.058 Models A-B); while, with reference to the expectations of export growth in 2024 the relationship is not significant (Model C).

Based on the provided results, Hypothesis 1 (H1)—which posits that *Digital innovation is positively associated with firms' export capabilities in terms of probability of exporting and achieving export growth* —is partially confirmed. Data show that digital innovation is positively associated to the probability of exporting, with a positive and statistically significant marginal effect (ME: 0.058, p<0.01). This confirms the first part of the hypothesis, that firms investing in digital innovation are more likely to export than those that do not. However, regarding the rise of exports, the relationship is weaker. While digital innovation shows a statistically significant relationship with export growth in 2023 (p<0.05), the effect is less pronounced (ME: 0.038). Furthermore, there is no significant relationship between digital innovation and expected export growth in 2024 (Model C). Thus, while digital innovation is clearly related to the probability of exporting, its relationship

with the export growth is less consistent and not as strong, meaning that H1 is confirmed for export probability but only partially supported for export growth.

Table 4 - Digital Innovation Effect

	EXP	EXP_GROWTH_23	EXP_GROWTH_24
	(A)	(B)	(C)
DIGITAL	0.058***	0.038**	0.021
	(0.016)	(0.017)	(0.017)
+ controls			
Obs	2,448	2,448	2,448
Wald chi2	565.66***	197.19***	228.00***
Pseudo R2	0.255	0.078	0.092

Dependent variable at the top of the column. The table displays: i) average marginal effects after probit regression; ii) robust standard errors in parentheses; iii) Wald Chi-square testing the joint significance of the explanatory variables. *** p < 0.01, ** p < 0.05, * p < 0.1.

Deepening the digital innovation by a perspective based on the intensity - measured by the number of 4.0 technologies firms invested into - we find that export capabilities increase as the number of 4.0 technologies increase. The probability of exporting (setting as reference category the firms not investing in digital innovation) rises passing from investing in only one technology to three and over (7.3% to 12.4%, Table 5, Model A). What is most interesting is the existence of a positive and significant relationship – much more than considering the digital innovation in binary terms as investigated before – of the digital intensity with the export performances. Only the firms that have invested in more than one 4.0 technology have a higher probability (statistically significant at 1%) of achieving an export increase, with a rise in magnitude passing from the case of investing in two technologies to three and over (Models B-C).

Table 5 - Digital technological intensity effect

	EXP	EXP_GROWTH_23	EXP_GROWTH_24
	(A)	(B)	(C)
Digital_1	0.073***	0.032	0.021
	(0.020)	(0.020)	(0.019)
Digital_2	0.109***	0.091***	0.105***
	(0.025)	(0.025)	(0.025)
Digital_3over	0.124***	0.102***	0.143***
	(0.031)	(0.031)	(0.032)
+ controls			
Obs	2,448	2,448	2,448
Wald chi2	577.68***	210.70***	256.66***
Pseudo R2	0.261	0.083	0.104

Dependent variable at the top of the column. The table displays: i) average marginal effects after probit regression; ii) robust standard errors in parentheses; iii) Wald Chi-square testing the joint significance of the explanatory variables. Concerning the main independent variable, *Digital_NO* is the reference category. *** p < 0.01, ** p < 0.05, * p < 0.1.

The training proves to be a key complementary factor of digital innovation in supporting export capabilities (Table 6). Specifically, our findings show that only the firms that have accompanied investments in 4.0 technologies with activities of training skills are more likely to export: the marginal effects of the variable *Digital_with_skills* are positive and statistically significant (ME: 0.064, p<0.01, Table 6, Model A), in contrast to the one related to the variable *Digital_no_skills*. This evidence also emerges if we look at the probability of registering export growth in 2023 (Model B). Based on the provided information, Hypothesis 2 (H2)—which posits that *The combination of digital innovation and employee training is positively associated with firms' export capabilities in terms of probability of exporting and achieving export growth* —is confirmed.

Green innovation shows some similarities with digital innovation, because it is key factor for exporting much more than for the export growth (Table 7). In particular, the probability of exporting of the firms that have invested in green innovation, in comparison to the others, is higher and statistically significant (ME 0.06, p<0.01, Table 7 , Model A); while in the case of the likelihood of registering an export growth there is not any significant difference between these two groups of firms (Models B-C). Thus, based on these results, Hypothesis 3 (H3) – which posits that *Green innovation is positively associated with firms' export capabilities in terms of probability of exporting and achieving export growth* —is partially confirmed.

Table 6 - Green innovation effect

	EXP (A)	EXP_GROWTH_23 (B)	EXP_GROWTH_24 (C)
GREEN	0.060***	0.033	0.021
	(0.016)	(0.024)	(0.024)
+ controls			
Obs	2,448	2,448	2,448
Wald chi2	566.78***	57.98***	73.30***
Pseudo R2	0.026	0.027	0.034

Dependent variable at the top of the column. The table displays: i) average marginal effects after probit regression; ii) robust standard errors in parentheses; iii) Wald Chi-square testing the joint significance of the explanatory variables. *** p < 0.01, ** p < 0.05, * p < 0.1.

Focusing on the different types of green innovation (Table 8), we find important synergies between eco-process and eco-product innovation: the highest likelihood of exporting – with the highest level of statistical significance (at 1%) – arises when the firms invested in both of these two types of green innovation (ME of *Green_product&process*: 0.141, p<0.01, Table 8, Model A). While, with respect to the export growth capabilities, no type of green innovation (*Green_only_process*, *Green_only_product*), also taking into account the synergies (*Green_product&process*), has a significant relationship.

Table 7 - Eco-process and eco-product innovation: the role of synergies

	EXP	EXP_GROWTH_23	EXP_GROWTH_24
	(A)	(B)	(C)
Green_only_process	0.041**	0.039	0.023
	(0.018)	(0.026)	(0.026)
Green_only_product	0.068	0.019	0.087
	(0.049)	(0.064)	(0.067)
Green_product&process	0.141***	0.022	-0.008
	(0.029)	(0.037)	(0.036)
+ controls			
Obs	2,448	2,448	2,448
Wald chi2	568.41***	58.40***	74.80***
Pseudo R2	0.259	0.027	0.035

Dependent variable at the top of the column. The table displays: i) average marginal effects after probit regression; ii) robust standard errors in parentheses; iii) Wald Chi-square testing the joint significance of the explanatory variables. Concerning the main independent variable, *Green_NO* is the reference category. *** p < 0.01, ** p < 0.05, * p < 0.1.

Finally, we investigated if there are some synergies between digital and green innovation in supporting export capabilities. Our results show that complementarity is a key factor for export growth: only the firms that have invested in both digital and green innovation have a higher probability, and statistically significant, of registering an increase in export in 2023 as well as in 2024 (ME of *D&G* p<0.01, Table R.9, Models B-C). In the case of investing in only one of the two types of innovation (*DG_only_digital*, *DG_only_green*), we don't find any significant relationship with the export growth (Models B-C).

Considering the capability of exporting, we find that, despite the investment in only digital innovation (*DG_only_digital*) as well as in only green innovation (*DG_only_green*) show a significant relationship with the probability of exporting, the magnitude reaches the highest level in the case of twin innovation (*D&G_both*) (ME: 0.094 vs 0.010 and 0.076, Model A). Based on the provided results, Hypothesis 4 (H4) - *The combination of digital and green innovations is positively associated to firms' export capabilities in terms of probability of exporting and achieving export growth* - is confirmed. The results indicate a significant synergy between digital and green innovations in supporting firms' export capabilities. Firms that have invested in both digital and green innovations show a statistically significant higher probability of export growth in both 2023 and 2024 (ME of D&G p<0.01, Table R.6, Models B-C). In contrast, firms that invested in only one of the two types of innovation (either digital or green) did not exhibit a significant relationship with export growth.

Regarding the probability of exporting, while firms that invested only in digital or only in green innovation showed a positive relationship, the effect was much and more substantial for firms that invested in both (ME: 0.094 for twin transition vs. 0.010 for digital-only and 0.076 for green only, Model A). This suggests that the

combined adoption of digital and green innovations provides the most significant boost to export capabilities in terms of entering new markets and increasing export volumes.

Table 8 - The role of synergies

	EXP	EXP_GROWTH_23	EXP_GROWTH_24
	(A)	(B)	(C)
DG_only_digital	0.076***	0.022	0.019
	(0.022)	(0.023)	(0.023)
DG_only_green	0.090***	0.028	0.038
	(0.026)	(0.027)	(0.028)
D&G_both	0.094***	0.069***	0.048**
	(0.022)	(0.023)	(0.022)
+ controls			
Obs	2,448	2,448	2,448
Wald chi2	574.20***	200.87***	228.12***
Pseudo R2	0.260	0.080	0.093

Dependent variable at the top of the column. The table displays: i) average marginal effects after probit regression; ii) robust standard errors in parentheses; iii) Wald Chi-square testing the joint significance of the explanatory variables. Concerning the main independent variable, *DG_NO* is the reference category. *** p < 0.01, ** p < 0.05, * p < 0.1.

In summary, we find a positive relationship between digital and green innovation and exporting capability. This evidence becomes stronger in some cases when the firms invest in: i) more technologies than in only one; ii) skills training combined with the technologies than in only technologies; iii) in both eco-process and eco-product innovation than in only one of these; iv) in both digital and green innovation than in only one of these. For export growth, digital and green innovation don't generally show a significant and positive relationship, but the relationship becomes significant when the firms invest in i) two or more technologies rather than in only one, ii) in both digital and green innovation rather than in only one of type if innovation.

5. Conclusions

The paper examines the relationship between digital and green innovations and firms' export activities. To this end, two research questions are addressed: firstly whether these innovations facilitate export activities, and secondly, whether they assist existing exporters in increasing their export volumes.

Our research findings contribute to a deeper understanding about the relationship between digital and green innovations and export performance. They indicate a generally positive correlation between these innovations and a company's capacity to export. The evidence is strong when firms invest in multiple technologies simultaneously, rather than relying on a single innovation. Furthermore, firms that complement their technological investments with employee training are better positioned to capitalize on innovations fully,

maximizing their export potential. Therefore, companies aiming to penetrate export markets should adopt a comprehensive approach integrating technological advancements with human capital development.

Furthermore, our analysis shows that firms investing in both eco-process and eco-product innovations are more likely to succeed in exporting than those focusing on just one type of innovation. Similarly, a strategy that combines digital and green innovations is more effective than a focus on either one alone. This result is in line with the study of Dou and Gao (2023), where they examined the interplay between digital technologies and green technology innovation, particularly among manufacturing firms and found that is essential to recognize digital transformation as a critical catalyst for driving green transformation. These findings indicate that a comprehensive and integrated approach to innovation, which incorporates multiple facets of a firm's operations, is more likely to yield favourable results in export initiation. However, while these innovations do not consistently show a strong relationship with export growth, they have a positive effect in specific cases. Our analysis indicates that firms that invest in multiple technologies or combine digital and green innovations are more likely to experience growth in export volumes. This suggests that the scope and integration of innovation efforts are crucial for driving export growth rather than innovation in isolation.

Although the study offers valuable insights, its limits arise from its exclusive focus on Italian manufacturing companies. To validate and broaden our findings, future research could investigate similar hypotheses in various industrial contexts and countries. Furthermore, longitudinal research would be more effective in capturing the temporal development of export capabilities, thereby providing an evolving perspective on the influence of digital and green technologies on firm performance in changing market conditions.

The results imply that policymakers should endorse programs that promote companies to embrace broad innovation strategies that integrate digital and environmentally friendly technology. Providing subsidies or tax incentives for integrative innovations has the potential to accelerate the participation of companies in global marketplaces. Moreover, the implementation of educational and training programs that improve skills associated with emerging technologies can play an important part in maximizing the potential of these advances. By promoting an integrated approach to innovation, governmental actions can enhance the competitive advantage of companies in international markets, promoting sustainable and advanced export industries.

Not only public innovation policies have the potential to increase firms' competitive advantage, but also managers should become fully aware of the potentialities of twin innovations and of the advantages of developing green products for opening new markets and increase competitive advantages (Siba Borah et al., 2024). Managers should recognize that these innovations are not isolated drivers but work synergically, especially when complemented by investments in employee training. Training programs tailored to digital and green technologies can empower employees to fully leverage these advancements, translating them into tangible benefits such as increased export initiation and growth. At the business level, firms should be capable to exploit the new wave of digital technologies for the introduction of new environmentally sustainable production processes and models (Montresor & Vezzani, 2023).

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