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Artificial Intelligence and exporting performance: Firm-level evidence from Portugal

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Abstract

The adoption of new digital technologies offers new opportunities and has the scope to engender positive effects on firms' expansion and success in international markets. This paper examines the main factors driving the adoption of Artificial Intelligence (AI) and AI-related digital technologies that enable the Industry 4.0 transformation and whether these new generation of digital technologies affect exporting performance at firm level. Using a rich and representative sample of Portuguese firms over the period 2014-2020, the estimated results suggest that firm's ex-ante performance, digital infrastructures and in-house ICT skills are the main drivers of digitalisation. However, conditional to ex-ante firm's performance, there are heterogenous effects on exporting performance across digital technologies and across industries. Moreover, there is evidence of positive selection towards large firms, casting doubts on the inclusiveness of the adoption process and the performance effects of AI and AI-related technologies.

JEL Classification: L20, H81, L25

Keywords: Artificial Intelligence, Industry 4.0 enabling digital technologies, firms' exporting performance

Note: ***This article is sole responsibility of the authors and do not necessarily reflect the positions of GEE or the Portuguese Ministry of Economy*.**

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1. Introduction

The debate on the adoption and diffusion of digital technologies and their economic impacts is flourishing, with different perspectives and topics under scrutiny. The growing digitisation of economic activities offers new opportunities to reactivate or, even, foster the technological diffusion machine, as it makes business trialling faster and cheaper and the possibility of replicating innovations faster and more accurate (Brynjolfsson & McAfee 2012). If so, the adoption of new digital technologies, with a particular focus on Artificial Intelligence (AI) and AI-related digital technologies, could engender positive effects on firms' productivity and, hence, on their expansion and success in international markets, given that internationalisation is widely recognised as a key success factor of firms.

By representing a fundamental technological shift, there are good reasons to believe that the new digital technologies should have the power to engender strong positive effects on productivity (Syverson 2011, Brynjolfsson & McAfee 2014) and on firms' international involvement. Innovation is how the productivity growth happens and many innovations emerge from recombining existing solutions and elements in order to make them more valuable. Digital technologies assist this kind of innovation by making it easier to combine ideas, to dissimilate them, and to create value from them. When firms began to make widespread efforts to integrate the new generation of digital technologies into their business, for example by embedded AI into business processes, automation of certain routine tasks, and on the exploration of massive amount of data in order to improve product quality, to seize new opportunities with innovative ways to reach and better match customers' needs, and reducing costs of interacting with suppliers and customers, productivity gains are likely to emerge (Bartel et al. 2007, Akerman et al. 2015). Further, the entry costs and business barriers related to the involvement in international markets are likely to decreasing (Cassetta et al. 2020) as a greater logistical efficiency and better connection of supply and demand have the potential to emerge.

Yet, the empirical evidence on the interconnection of AI and new emerging and AI- related digital technologies with international involvement at the firm level is scarce, yielding mixed findings with scope to diverse explanations and many directions of further research (see, for instance, Alguacil et al. 2022, Cassetta et al. 2020, DeStefano & Timmis 2021, Teruel et al. 2022). Digital technologies tend to engender productivity gains, efficiency gains along supply chains and reductions in trade costs only in com- bination with other factors such as organisational and management skills (e.g., Bloom et al. 2012), R&D and intangible investments (e.g., Corrado et al. 2017) and regulatory environment that enables the efficient resources reallocation (e.g., Bartelsman 2013). In addition, digital technologies are a heterogeneous set of technologies that may affect firms' productivity and exporting performance in different ways. Therefore, previous evidence points out that the links between digital adoption and productivity and, hence, exporting performance, are complex (for a survey, see, e.g., Gal et al. 2019) and deserve further empirical research.

The objective of this paper is three-fold. Firstly, we take a broader perspective and investigate the main factors explaining differences in the adoption of AI and other Industry 4.0 enabling digital technologies at firm level for a representative sample of Portuguese firms over the period 2014-2020. Using micro-level information on adoption of digital technologies allow us to offer a more fine-grained and more far-reaching understanding of the main factors driving adoption and its economic implications. The new emerging digital technologies under scrutiny are a set of heterogenous technologies that allow an integration between manufacturing operations systems and information and communication technologies (ICT). Especially, among others, artificial intelligence, machine learning, and AI-related technologies embedded in autonomous robots and the Internet of Things (IoT), form the concept of Industry 4.0. Second, we investigate the impact of AI and AI-related digital technologies enabling Industry 4.0 transformation on the intensive (level of foreign sales) margin of exports. Our approach differs from previous works on the impact on ICT on exporting behaviour as it focuses on the phenomenon of digitalisation based on AI and other Industry 4.0 enabling technologies as well as investments in digital skills and infrastructures. Focusing on AI and other Industry 4.0 enabling technologies and exporting performance at firm-level, our analysis has scope to provide a better understanding of heterogeneity at adoption and its interconnection with firms' international involvement. In addition, we explore whether there are differences in the intensive margin of exports due to the adoption of AI and AI-related new emerging digital technologies among firms belonging to different industries.

As far as we are aware, there is no similar study applied to Portugal, a developed country but, in the context of the European Union (EU), a small, open, and peripheral economy. In fact, the Portuguese case is of particular importance, given the public incentives to firms' digitalisation and firms' export exposure, both of which are linked to a relevant involvement in global value chains. Assessing the impact of AI and AI-related digital technologies on firm-level exporting performance is crucial and could contribute significantly to the ongoing debate on the interconnection of digitalisation with exporting activities and performance. In addition, it could offer important implications for public policy related to the support of digital adoption, the expansion of international engagement, and a deeper integration in international markets. To date, there is only some initial evidence and for a restrict number of technologies that the new emerging digital technologies have positive economic effects.

The paper is organised as follows. Section 2 presents an overview of the links between new emerging digital technologies and exporting performance. Section 3 describes the data, empirical variables, and provides a description of digital technologies adoption by Portuguese firms. Section 4 describes the empirical strategy. Subsequently, econometric results are presented and discussed in Section 5. Section 6 concludes.

2. Digitalisation and international engagement

The adoption of digital technologies entails important changes in firms' comparative advantages and on the geographic organisation of the business, with the scope to engender decreasing costs of making business across different locations (Autio et al. 2021) and to overcome a possible lack of economies of scale due to mass customisation (Fogliatto et al. 2012). Very recent studies, (see, for instance, Calvino & Fontanelli 2023, Cefis et al. 2023, Cirillo et al. 2023, Forgione & Migliardo 2023) point out gains in productivity, sales growth, and wages for firms adopting the new generation of digital technologies, such as AI and/or AI-related digital technologies. Despite the potential positive impact on firms' performance, their adoption is not instantaneous, implementation lags could arise, and it may not be inclusive.

As digital technologies can be seen as an example of General Purpose Technologies - technologies that are introduced very infrequently but they can have a significant impact on firms and on an economy as a whole -, it is expected to take time to spread across firms and markets. Their radical nature usually implies a destruction of old routines and old capital, the availability of complementary resources (e.g. digital skills and infrastructures) and internal organisation adjustments for a successful deployment of such technologies (Bresnahan et al. 2002, Bloom et al. 2012). The availability and diffusion of complementary resources to firms, other firm-specific characteristics, as well as the external context in which firms operates (e.g. competition and cumulativeness of knowledge) have been identified in the technology diffusion literature as important factors driving technology adoption decisions (see, for instance, Malerba & Orsenigo 1996).

In particular, the potentially high risk and fixed cost related to digital technologies adoption (Brynjolfsson et al. 2021) may impose a selection towards larger and less financially constrained firms. In turn, smaller firms seem to be in a worse position to adopt digital technologies as they tend to be more financially constrained, with reduced scope to innovation complementarities, resulting more constrained in leveraging AI and AI-related digital technologies. However, Cirillo et al. (2023) suggest that small firms could gain more from technology adoption as larger firms take more time to notice the effect of their technological investments. Accordingly, firm's size - a measure of ex-ante firm's performance - seems to be a good predictor for digital technologies adoption, supported by a number of empirical studies that found a positive correlation between firm size and technology adoption (e.g., Fabiani et al. 2005, Zolas et al. 2020).

Another important issue is that a necessary prior condition for adopting the new generation of digital technologies is sufficient computing power and access to ultra- fast broadband to handle and to exploit massive quantities of digital information in these digital infrastructures are important firms' capabilities in leveraging the impact of new digital technologies, which can further promote exports (Sanderson et al. 2022). In the same line, the upgrading and increasing sophistication on digital technologies adoption requires complementary assets such as skill-specific labour or organisational adjustments (Bloom et al. 2012, Akerman et al. 2015).

Although potentially correlated with firm's size, the deployment of digital structures and in-house ICT skills are firm- specific capabilities that shifted the cost structure and use of digital technologies and, hence, could be a relevant driver of the digital adoption process.

From a firm-level perspective, digital technologies may affect a firm's international engagement through several channels. In particular, AI and AI-related digital technologies enabling Industry 4.0 transformation are likely to engender flexible manufacturing processes, to ease the analysis of data in real time, leading to a reduction on operational costs and on the uncertainty of decision-making (Dalenogare et al. 2018, Sanderson et al. 2022). Moreover, digital technologies assist innovations that emerge from recombining existing knowledge and solutions, making it easier to combine ideas and to make them more valuable. By improving business processes, reducing operational costs, reducing search costs and informational frictions (Fernandes et al. 2019, Sanderson et al. 2022) and have faster adaptation to changes in the market and consumer preferences, digital technologies may affect exporting performance by generating additional foreign sales and making easier the entry in international markets. For instance, looking at the robot technologies, Koch et al. (2021) identify a sizeable productivity effect that entails that robots raise the efficiency in production, and thus important changes in firm's competitive advantage in international markets can arise. Their empirical findings are compatible with a complementarity between robot adoption and exporting performance.

On the other hand, Strange & Zucchekka (2017) argue that the new generation of digital technologies, leading to the concept of Industry 4.0, has potential to transform internationalisation processes by affecting the organisation of activities within global value chains and leading to new configurations involving suppliers, firms and customers. In the same line, Buchi et al. (2020) assess the impact of the degree of openness towards Industry 4.0 on firm's performance, concluding that Industry 4.0 enabling technologies have scope to engender new opportunities in terms of production flexibility and improved product quality. The number and complementarity in the use of the new generation of digital technologies seem to be a driver for firms to adopt and to leverage their performance gains (Cho et al. 2023). Overall, the adoption of the new generation of digital technologies may lead to product quality improvements as they often require higher quality inputs (DeStefano & Timmis 2021), allow firms to create and virtually examine the feasibility and value of more sophisticated products, and enable greater accuracy and precision on production. Nonetheless, the product quality gains from adoption of new generation of digital technologies will depend on the radicalness of new technologies when compared with the prior technology used and on the availability of digital skills to leverage adoption gains.

3. Data and empirical variables

Two main panel datasets, provided by the Portuguese National Institute of Statistic (INE) – *Inquérito à Utilização de Technologias de Informação e Comunicação nas empresas* (IUTIC) for digital adoption and *Sistema de Contas Integradas das Empresas* (SCIE) for firm-level productivity and other firm-specific characteristics -, are the basis for compiling the relevant data to compute our empirical variables. IUTIC is part of the Community Survey on ICT Usage and E-Commerce and is an annual survey conducted since 2004. In Portugal, this survey is a census for large firms (with more than 250 employees or turnover larger than 25 million euros) and a stratified random sample based on size and industry affiliation for other firms. The survey is compulsory by law for selected firms, which makes it a reliable, rich and valuable dataset. The survey encompasses several questions related to e-commerce and developments in digital technologies' usage in enterprises that allow us to assess the adoption of digital technologies in transforming business, firms and economic performance.

Looking at digital technologies, the survey comprises several questions that goes from a simple internet usage to a more sophisticated and intensive usage of digital technologies, such as cloud computing, robots, big data collected from digital social media, sensors or other digital devices, or digital technologies to share information among firm's departments and customers. We interpret the answer to these questions as indicating that a firm adopts digital technology that could affect a firm's performance. In particular, to our purpose, we focus on AI and AI-related digital technologies enabling an Industry 4.0 approach. These questions have been intermittently available since 2014. Therefore, the time span of our main analysis is the period 2014-2020, even though with the gaps for different variables.

We then match IUTIC firm-level data with data from SCIE, which is an annual census for Portuguese firms, encompassing a rich set of firm-level information such as employment and workforce characteristics, foreign sales, and the industry in which firms operate according to the NACE classification (Classification of Economic Activities in the European Union). This set of information is the basis for computing variables affecting export performance such as firm size, apart from our variables of interest related to digital technologies adoption, ICT skills and digital infrastructure.

As both datasets include the same unique firm identifiers, we are able to trace firms over time and conduct the empirical assessment. We match 30,377 unique firms for which we have intermittent information on digital technologies adoption. This intermittency is due to variations on the IUTIC survey design and sampling scheme. Therefore, our final sample consists of 42,940 firm-year observations, where 7,799 (25,68%) firms are observed in at least two years. Table A.1 in Appendix A describe the measurement and source of the empirical variables used in the analysis, whereas Table 1 reports some descriptive statistics for dependent and control variables, averaged over all firm-year observations and over several different partitions of the data. For each partition, the last column shows the statistical difference (given by a t-test) of the means of these variables for the types of firms identified.

Table 1: Descriptive statistics of empirical variables

	All firms		Large firms		Young firms		No-exporting firms	
	Mean	Sd.	Mean	Diff.	Mean	Diff.	Mean	Diff.
Exporting variables								
Exporting performance	5,679	6,847	11.207	6.276***	3.873	-2.011***	-	-
No-exporting firms (0/1)	0.625	0.484	0.399	-0.257***	0.747	0.136***	-	-
Digital technologies variable								
Industry 4.0 (0/1)	0.083	0.276	0.192	0.123***	0.086	0.004	0.055	-0.065***
ICT skills								
ICT specialists (0/1)	0.310	0.462	0.776	0.532***	0.201	-0.121***	0.184	-0.276***
ICT training (0/1)	0.253	0.435	0.598	0.393***	0.168	-0.094***	0.172	-0.179***
Digital infrastructure								
Ultra-Fast Broadband (0/1)	0.418	0.492	0.500	0.101***	0.479	0.074***	0.428	0.039***
Cloud computing adopter (0/1)	0.166	0.372	0.336	0.192***	0.163	0.004	0.157	-0.024***
Other empirical variables								
Firm's size	2.840	1.927	6.360	4.000***	2.061	-0.867***	2.313	-1.406***
Firm's turnover	14.261	2.491	17.732	3.939***	13.049	-1.344***	14.262	-2.300***

Notes: ***. **, * indicate that the difference in means is statistically significant at the 1%, 5%, 10%, respectively.

Overall, Portuguese firms report a modest rate of adoption of Industry 4.0 enabling technologies, with a slight increase in the case of large firms and exporting firms. Moreover, young firms seem not to explore differently this technological shift to engender competitive advantage, when compared to older firms. This modest rate of adoption suggest that the performance and efficiency of Portuguese firms could be strongly compromised. On the side of digital infrastructures, the access to ultra-fast broadband seems to be, to some extent, widespread across firms, with large, young and non-exporting firms as being the more intensive users, when compared with their counterparts. Nonetheless, non-exporting and young firms appear to not take full advantage of this digital infrastructure as they do not report superior adoption rate of Industry 4.0 enabling digital technologies. Consistently, those firms report lower ICT skills, which could be interpreted a indicating that the process of digitalisation deepness is still at the beginning, with, potentially, a low degree of sophistication and combinations of use of the new generation of digital technologies. A very different picture can be recognised from the large firms, which, on average, report higher ICT skills, higher digital infrastructure and, accordingly, higher adoption of Industry 4.0 enabling digital technologies. These differences could be interpreted as suggesting that small, young and no-exporting firms are at a more initial stage of digital technologies adoption process.

On the other hand, Portuguese firms reveal a small engagement in international markets, and, hence, reduced exposure to more competitive markets. It could be seen as an indicator of fragile incentives to adopt Industry 4.0 enabling technologies. Only 37.5% of the firms are exporters and, for them, the average of exporting performance does not exceed 40% of their average turnover, indicating that there is a large scope to expand activity in international markets and, potentially, performance. More importantly, young firms have a smaller exposure to international - more competitive - markets, suggesting some difficulty to overcome barriers in operating in these markets with statistically significant and negative impact on turnover and on the ability to shorten the gap to their counterparts.

This heterogeneity in terms of firm's resources, competences, and incentives could be seen as having predictive power for the heterogenous probability of adoption industry 4.0 enabling technologies and exporting performance, measured by foreign sales per employee.

4. Empirical strategy

In order to assess the main drivers of Industry 4.0 enabling technologies, a series of linear probability models were estimated. The estimating equation is

$$Y_{i,t} = a + b_1 SizeClass_{i,t} + ICTSkills_{i,t} + Infrastructure_{i,t} + D_t + D_s + e_{i,t}$$

where Y is a binary variable for AI and AI-related digital technologies enabling the Industry 4.0 transformation, *SizeClass* are also binary variables based on size, $ICTSkills$ are binary variables for having employees with ICT specific skills and if a firm reports as providing ICT training for non-ICT specialists, *Infrastructure* are binary variables for having a fixed internet connection speed for downloads equal or above 100 Mibts/sec and for contracting and using cloud computing services, while D_s and D_t identifies sector and year fixed effects. Subscripts i identifies the firms and t the year. The use of *SizeClass* rather than its continuous version has the potential to mitigate potential endogeneity issues due to the correlation with firm's contemporaneous performance. Moreover, the existence of possible threshold effects in adopting digital technologies, due to fixed costs or economies of scale in the adoption process, are more likely to emerge when using size classes rather than continuous measure of firm's size (Calvino & Fontanelli 2023).

On the side of exporting performance regressions, the extended performance linear regressions, one for each Industry 4.0 enabling technology, are defined as

$$log(Exports)_{i,t} = a + b_1 Adopter_{i,t} + SizeClass_{i,t} + NumberDTs_{i,t} + D_t + D_s + e_{i,t}$$

where the dependent variable is a measure of performance in international markets defined as firm's foreign sales per employee, the main variable of interest is a indica- tor of adoption of AI and AI-related digital technologies, and as control variables the regression includes binary variables based on firm's size and a variable counting the overall number of digital technologies used at firm level (excluding the digital technology under scrutiny) as a proxy of firm digitalisation and complementarities in the use of digital technologies (Cho et al. 2023). The existence of complementarities between overall digitalisation and the adoption of other digital technologies is also suggested by (Brynjolfsson et al. 2021), which have scope to impact on firm's exporting performance. The need to develop a series of complementary assets and capabilities, either related to digital capabilities or organisational resources, to further exploit the new generation of digital technologies may help firms to upgrade on intangible resources that eases the extraction of performance gains from the international engagement. Each regression also controls for 2-digit sector and year fixed effects.

5. Digital technologies and exporting performance

Here, the empirical results related to the main factors explaining the adoption of AI and AI-related digital technologies and the relationship between those digital technologies adoption and exporting performance are presented and discussed. In the first stage, the potential positive selection, based on ex-ante better performing firms (proxied by firm's size) and the explanatory power of firm's digital infrastructures and skills are addressed and discussed. This offers a more fine-grained and more far-reaching understanding of the main factors driving AI and other Industry 4.0 enabling technologies adoption and adds to the debate on the inclusiveness of digital technologies adoption. Next, the impact of firm's digitalisation profile related to the adoption of AI and other Industry 4.0 enabling technologies (jointly or separately considered) on exporting performance at firm level are examined in order to provide a better understanding of heterogeneity at adoption and its interconnection with firms' international involvement. At the end, the possibility of heterogenous effects of AI and AI-related digital technologies on the extensive margin of exports due to inter-industry heterogeneity is explored in order to add to the ongoing debate on the economic impacts of AI and digitalisation.

5.1. Capabilities and incentives on the adoption process

Although there are several factors that would have power to explain the heterogenous profile of digital technologies adoption at firm level, here special attention is on ex-ante diversity of performance (based on firm's size) and digital capabilities and incentives. Table 2 shows the estimates for the effect of firm's size, capabilities, and incentives at firm-level in driving the probability of adoption of AI and AI-related digital technologies enabling the Industry 4.0 transformation.

Table 2: Adoption of Industry 4.0 enabling technologies: estimated effects

	Industry 4.0 technologies						
	I4.0	Robots	Big Data	3D Printing	Machine Learning	Artificial Intelligence	Internet of Things
Size class 20-49	0.019**	0.005	0.024**	0.009	0.144	-0.014	0.019
	(0.008)	(0.011)	(0.011)	(0.008)	(0.092)	(0.020)	(0.022)
Size class 50-249	0.033***	0.055***	0.021*	0.010	0.055	0.014	0.085***
	(0.008)	(0.012)	(0.011)	(0.007)	(0.085)	(0.019)	(0.021)
Size class 250+	0.083***	0.118***	0.090***	0.039***	0.162*	0.085***	0.176***
	(0.010)	(0.015)	(0.015)	(0.010)	(0.084)	(0.023)	(0.025)
Ultra-Fast Broadband (>= 100 Mibts/sec)	0.037***	0.021**	0.045***	0.017***	0.025	0.041**	0.032*
	(0.006)	(0.021)	(0.009)	(0.006)	(0.054)	(0.014)	(0.018)
Cloud Adopter	0,085***	0.027***	0.136***	0.015***	0.020	0.111***	0.198***
	(0.007)	(0.009)	(0.010)	(0.007)	(0.052)	(0.092)	(0.017)
ICT Specialists	0.070***	0.091***	0.085***	0.025***	-0.078	-	-
	(0.007)	(0.011)	(0.011)	(0.007)	(0.059)		
ICT Training (for other employees)	0.037***	0.023***	0.076***	0.030***	0.126**	-	-
	(0.007)	(0.009)	(0.010)	(0.007)	(0.049)		
Observations	15,055	6,073	9,253	6,073	571	3,675	3,675
R^2	0.230	0.259	0.135	0.114	0.194	0.071	0.112
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The adoption regressions are linear probability models that employ a dummy variable for each digital technology as dependent variable and includes size, other firm-specific characteristics, and relevant digital skills and infrastructures as main explanatory factors. The dummy variable "I4.0" takes value 1 if a firm adopts any of the six digital technologies related to Industry 4.0 technologies under scrutiny. Each regression includes 2-digit sector and year fixed effects. Robust standard errors in parenthesis. Significance levels: *, 10%; **, 5%; ***, 1%.

Overall, the estimated results suggest that ex-ante performance, digital capabilities and skills at firm-level are relevant factors explaining AI and Ai-related digital technologies adoption, considered separately or jointly. Moreover, additional logit models have been estimated as robustness checks, qualitatively confirming the main findings reported.

There seems to be relevant evidence for positive selection as ex-ante large firms (i.e. ex-ante better performing firms) are more likely to adopt any Industry 4.0 enabling technology, as has already been put forward by Brynjolfsson et al. (2021). This skew- ness in AI and AI-related digital technologies adoption towards large firms suggests that these technologies could have a disproportionate economic impact despite their generally low adoption rates. As large firms are more prone to be exporting firms, the aggregated impact of digital technologies adoption on exporting performance could be more substantial.

On the other hand, this skewness toward large firms discloses a lack of inclusiveness on the adoption process. In fact, the probability of small firms adopting most of the AI and AI-related digital technologies is quite low or null, suggesting that possible reduced complementary innovation resources constrain small firms' incentives to adoption. Big Data technology seems to be an exception, suggesting that small firms are able to leverage and extract benefits from the exploitation of massive quantities of digital data.

Yet another interesting finding is that only the largest firms are significantly more likely to adopt AI and 3D Printing (and, to some extent, Machine Learning) technologies with respect to other firms of different sizes. This could be interpreted as indicating that those digital technologies are at the very early stage of adoption by Portuguese firms and only largest firms are able to deal with their high risk and fixed cost.

The empirical results, on the other hand, confirm that the internal digital capabilities related to the deployment of digital infrastructures and in-house ICT skills are important firms' capabilities in shaping the probability of adoption. The impact of these capabilities on the Industry 4.0 enabling technologies adoption process is transversal to almost all technologies under scrutiny. In particular, the availability of in-house ICT skills (either among ICT specialists or other employees) and its impact of digitalisation suggest that adopters of AI and AI-related technologies are firms pursuing an upgrading on the degree of sophistication and complementarities among digital technologies. As this degree of openness toward digital technologies is likely to engender greater opportunities in terms of production and product quality (Buchi et al. 2020), it can be interpreted as relevant incentives toward digitalisation and, in particular, the adoption of AI and AI-related digital technologies.

5.2. Digitalisation profile and its impact on firms' exporting performance

Another important perspective is to assess whether AI and AI-related digital technologies have an important role in shaping exporting performance and intensifying Portuguese firms' international engagement. Table 3 shows the estimated impacts of different digital technologies on exporting performance at firm-level, measured by foreign sales per employee.

Overall, the estimated results provide evidence on scale effects, regardless of digital technologies adoption. Firm's size is a strong driver of exporting performance, with the large firms reporting higher levels of foreign sales per employee, in line with previous evidence (see, for instance, Calof 1994, Wagner 1995). Moreover, the existence of scale advantages in the adoption of AI and AI-related digital technologies - see previous section - may enable the largest firms to better extract gains from international engagement due to digital technologies diffusion.

More importantly, there is relevant evidence that AI and AI-related digital technologies adopters are able to leverage such technological investments in international markets. AI and AI-related digital technologies, by ensuring massive information on customers and competitors in international markets and by engendering more flexibility and precision on manufacturing processes, have scope to impact on cross-border business operations. The exporting premium, nonetheless, seems to depend on the firm's digitalisation profile.

Upgrading the degree of openness and sophistication towards AI and AI-related digital technologies - measured here by the number of those digital technologies adopted by firms - increases export performance at firm level and may allow strengthening their position vis-`a-vis competitors. On the other hand, firms at the initial stage of the adoption process, adopting only one digital technology benefit diversely in terms of foreign sales per employee. Adopters of robots or 3D printing technologies attain higher exporting performance than non-adopters. But similar results cannot be found for adopters of other AI and AI-related digital technologies, reinforcing the argument that the digitalisation profile matters and some complementarity on adoption is required to extract economic benefits. In particular, more recent digital technologies, such as Artificial Intelligence (AI) or Internet of Things (IoT), may require a longer time span to engender exporting gains, when adopted separately from other digital technologies. Another possible explanation is that the adoption of other digital technologies by firms may indeed help them to develop the complementary assets that are needed to extract exporting gains from AI and IoT technologies, a finding that is in line with the findings of Cho et al. (2023).

Table 3: Exporting performance and digital technologies adoption

	Industry 4.0 technologies						
	I4.0	Robots	Big Data	3D Printing	Machine Learning	Artificial Intelligence	Internet of Things
Adopter=1	0.503***	0.698***	-0.422***	0.510***	0.474	0.163	-0.031
	(0.133)	(0.209)	(0.175)	(0.273)	(0.550)	(0.232)	(0.211)
Size class 20-49	1.010***	1.124***	1.039***	1.118***	-0.409	0.806***	0.813***
	(0.114)	(0.220)	(0.173)	(0.219	(0.967)	(0.303)	(0.307)
Size class 50-249	2.431***	2.127***	2.305***	2.137***	0.783	1.763***	1.771***
	(0.106)	(0.207)	(0.165)	(0.207	(0.857)	(0.283)	(0.285)
Size class 250+	2.621***	2.022***	2.303***	2.037***	0.266	2.035***	2.060***
	(0.030)	(0.237)	(0.190)	(0.237)	(0.863)	(0.326)	(0.329)
Number of other digital technologies	-	1.632***	4.339***	2.597***	5.341***	2.751***	3.007***
		(0.360)	(0.324)	(0.326)	(0.810)	(0.340)	(0.374)
Observations	21,730	6,196	9,410	6,196	619	3,765	3,707
R^2	0.344	0.358	0.356	0.351	0.45	0.340	0.337
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The exporting performance regressions are OLS models that that includes a (log) of sales in international markets per employee as dependent variable and industry 4.0 technologies adoption, size, and other firm-specific characteristics as main explanatory factors. The dummy variable "I4.0" takes value 1 if a firm adopts any of the six digital technologies related to Industry 4.0 technologies under scrutiny. Each regression includes 2-digit sector and year fixed effects. Robust standard errors in parenthesis. Significance levels: *, 10%; **, 5%; ***, 1%.

It is interesting to note that the adoption of robotic technologies, even in the case of no complementarities with the adoption of other digital technologies, raises significantly firm-level foreign sales per employee. This implies that the robot-adopting firm increases its presence in international markets and serves larger markets than non-adopters. This finding is in line to Koch et al. (2021) empirical evidence for Spanish firms and suggests that robotic technologies increase the scale of operations and, by this way, support productivity-enhancing innovations within firms. The adoption of 3D Printing technologies seems to work in a similar way. Our results highlight robotic and 3D Printing technologies as specific sources of exporting performance, which would impact future productivity gains.

As firms in different industries have dissimilar probabilities of adoption and exposure to international markets, AI and AI-related digital technologies can potentially affect industry heterogeneity in terms of international engagement and productivity path. Therefore, Table 4 shows the estimated impacts of different digital technologies over heterogenous industries in order to explore potential heterogeneity in digitalisation paths and its impact on firms' exporting performance.

By focusing attention on heterogeneity in digital technologies adoption within industries, the results provide evidence that firms in different industries benefit differently from AI and AI-related digital technologies. Technologies that involve a greater integration of data between firms, suppliers and customers, as is the case of IoT or AI, seem to engender exporting gains for firms in Professional & Scientific, Accommodation & Storage, and Wholesale & Retail industries. Robot and 3D Printing technologies, as being more related to manufacturing process and with scope to reduce operational costs, seems to be the main diver of exporting performance of firms operating in Manufacturing & Utilities industries. It is also interesting to note the positive effect on exporting performance of robot-adopter in Wholesale & Retail and Transport & Storage industries, suggesting that in these industries the effects of digital technologies adoption on operational costs, flexibility, and production time could be the main driving factors of exporting gains, as compared to no-adopters. This also reveal that the use of robots is gaining ground in the service industries, with positive impact on exporting performance.

Table 4: Exporting performance and digital technologies adoption across industries

	Industry 4.0 technologies						
	I4.0	Robots	Big Data	3D Printing	Machine Learning	Artificial Intelligence	Internet of Things
Manufacturing & Utilities	0.455***	1.943***	-0.870***	1.954***	0.558	0.508	-0.315
	(0.214)	(0.250)	(0.267)	(0.288)	(1.009)	(0.372)	(0.339)
Construction	-0.018	-0.296	0.070	2.287	2.451	-0.196	0.712
	(0.763)	(1.397)	(0.810)	(2.129)	(3.084)	(1.379)	(1.078)
Wholesale & Retail	1.111***	2.147***	0.992***	1.983	-1.159	0.994*	-0.561
	(0.341)	(0.711)	(0.353)	(1.276)	(1.175)	(0.563)	(0.487)
Transport & Storage	1.371*	2.630***	1.292	-2.452	4.891*	-0.167	1.101
	(0.768)	(1.297)	(0.800)	(2.838)	(2.466)	(1.367)	(1.130)
Accommodation & Food	0.161	-0.682***	0.222	1.586	3.957	0.401	1.713***
	(0.393)	(0.208)	(0.324)	(1.603)	(2.525)	(0.730)	(0.586)
Information & Communication	0.748	0.174	0.878*	-2.191	-0.044	1.050	-0.211
	(0.458)	(1.740)	(0.461)	(3.547)	(1.436)	(0.747)	(1.782)
Professional & Scientific	-0.319	-5.649*	-0.992	0.829	1.003	1.839*	2.254**
	(0.953)	(3.120)	(0.976)	(1.799)	(3.691)	(1.079)	(1.051)
Administrative & Real Estate	-0.347	-1.454	-0.302	2.023	2.503	0.729	0.225
	(0.550)	(1.246)	(0.568)	(2.085)	(2.329)	(0.879)	(0.808)

Notes: The exporting performance regressions are OLS models for each industry and includes a (log) of sales in international markets per employee as dependent variable and industry 4.0 technologies adoption, size, and other firm-specific characteristics as main explanatory factors. The dummy variable "I4.0" takes value 1 if a firm adopts any of the six digital technologies related to Industry 4.0 technologies under scrutiny. Each regression includes year fixed effects. Robust standard errors in parenthesis. Significance levels: *, 10%; **, 5%; ***, 1%.

Yet, on the services industries side, the results suggest that firms basing their business in exploiting massive quantities of digital information improve exporting performance mostly through Big Data technologies, which confirm that heterogenous digitalisation profiles are likely to engender exporting gains. This heterogeneity across AI and AI-related digital technologies and across industries also reinforce the argument that there is scope to positive effects on exporting performance at firm level, regardless of the not inclusive nature of the adoption process. The lack of inclusiveness is likely to exacerbate firm and industry heterogeneity, strengthening existing trends in industry concentration and weakening any possible catching-up process at work.

6. Concluding remarks and policy recommendations

Digital technologies, in particular AI and AI-related technologies enabling Industry 4.0, allow a faster adaptation to the changing productive and business environment and are significant pathbreaking innovations with expected sizeable effects on firm's performance and on the location and cross-border organisation of economic activities. Using a large-scale, representative sample of Portuguese firms, operating in manufacturing and services industries, between 2014 and 2021, this paper provides novel evidence on the main factors prompt firms to adopt AI and AI-related technologies enabling Industry 4.0 and on the size of the impact on exporting performance on adopting firms relative to non-adopting firms.

Our main contribution is the uncovering of heterogenous exporting effects across different digital technologies and different industries, which offer important insights to the ongoing debate about the effects of digitalisation on business performance and, in particular, international engagement. Overall, we found that ex-ante performance and in-house digital capabilities and skills are relevant factors shaping the probability of adoption. Moreover, the skewness toward large firms point out to the relevant issue of no-inclusive adoption process, which would impact on the aggregated gains from AI and AI-related technologies enabling Industry 4.0.

Looking at the impact of AI and AI-related technologies enabling Industry 4.0, on exporting performance, we found that the degree of openness and sophistication towards those digital technologies strengthen firm's position in international markets vis-á-vis competitors by increasing foreign sale per employee. This implies that some complementarity and diversity on adoption is required to leverage economic gains. Firms at the initial stage of the adoption process, adopting only one of those digital technologies, seem to find more difficulty to build unique competitive competences in order to engender exporting gains.

As our findings were based on large-scale data that is representative for a wide variety of manufacturing and service industries, we believe that this study makes important contributions to the innovation and trade literature and to the academic and public debate on productivity growth through increasing international engagement. In this sense, it is also valuable for policy makers and allows us to derive some policy implications. First, a broad policy mix affecting incentives and digital capabilities in a more intensive way and across a more general range of firms (in particular, small firms) would be needed to boost AI and AI-related digital technology adoption. This would include measures facilitating the access to and awareness about those technologies, improving cooperation in the adoption and diffusion process, and promoting the relevant complementarities existing between different digital technologies. Second, policy measures may foster returns from digitalisation to be more widespread across firms, supporting entry and competition in international markets.

References

Akerman, A., Gaarder, I. & Mogstad, M. (2015), 'The skill complementarity of broad-band internet', The Quarterly Journal of Economics 130(4), 1781–1824.

Alguacil, M., Lo Turco, A. & Martínez-Zarzoso, I. (2022), 'Robot adoption and export performance: Firm-level evidence from Spain', Economic Modelling 114, 105912.

Autio, E., Mudambi, R. & Yoo, Y. (2021), 'Digitalization and globalization in a turbulent world: Centrifugal and centripetal forces', Global Strategy Journal 11(1), 3–16.

Bartel, A., Ichniowski, C. & Shaw, K. (2007), 'How Does Information Technology Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement, and Worker Skills*', The Quarterly Journal of Economics 122(4), 1721–1758.

Bartelsman, E. (2013), 'ICT, reallocation and productivity', Economic Papers, Euro- pean Commission 486.

Bloom, N., Sadun, R. & Van Reenen, J. (2012), 'Americans do it better: US multinationals and the productivity miracle', American Economic Review 102(1), 167–201.

Bresnahan, T. F., Brynjolfsson, E. & Hitt, L. M. (2002), 'Information technology, work- place organization, and the demand for skilled labor: Firm-level evidence', The Quar- terly Journal of Economics 117(1), 339–376.

Brynjolfsson, E. & McAfee, A. (2012), Race against the Machine: How the Digital Revolution Is Accelerating Innovation, Driving Productivity, and Irreversibly Trans- forming Employment and the Economy, Digital Frontier Press.

Brynjolfsson, E. & McAfee, A. (2014), The second machine age: Work, progress, and prosperity in a time of brilliant technologies, W W Norton & Co.

Brynjolfsson, E., Rock, D. & Syverson, C. (2021), 'The productivity J-curve: How intangibles complement general purpose technologies', American Economic Journal: Macroeconomics 13(1), 333–72.

Buchi, G., Cugno, M. & Castagnoli, R. (2020), 'Smart factory performance and industry 4.0', Technological Forecasting and Social Change 150, 119790.

Calof, J. L. (1994), 'The relationship between firm size and export behavior revisited',

Journal of International Business Studies 25(2), 367–387.

Calvino, F. & Fontanelli, L. (2023), 'A portrait of AI adopters across countries', OECD Science, Technology and Industry Working Papers 2023/02.

Cassetta, E., Monarca, U., Dileo, I., Berardino, C. D. & Pini, M. (2020), 'The rela- tionship between digital technologies and internationalisation. evidence from italian smes', Industry and Innovation 27(4), 311–339.

Cefis, E., Leoncini, R., Marengo, L. & Montresor, S. (2023), 'Firms and innovation in the new industrial paradigm of the digital transformation', Industry and Innovation 30(1), 1–16.

Cho, J., DeStefano, T., Kim, H., Kim, I. & Paik, J. H. (2023), 'What's driving the diffusion of next-generation digital technologies?', Technovation 119, 102477.

Cirillo, V., Fanti, L., Mina, A. & Ricci, A. (2023), 'New digital technologies and firm performance in the italian economy', Industry and Innovation 30(1), 159–188.

Corrado, C., Haskel, J. & Jona-Lasinio, C. (2017), 'Knowledge spillovers, ICT and productivity growth', Oxford Bulletin of Economics and Statistics 79(4), 592–618.

Dalenogare, L. S., Benitez, G. B., Ayala, N. F. & Frank, A. G. (2018), 'The expected contribution of industry 4.0 technologies for industrial performance', International Journal of Production Economics 204, 383–394.

DeStefano, T. & Timmis, J. (2021), 'Robots and export quality', Policy Research Work- ing Paper 9678.

Fabiani, S., Schivardi, F. & Trento, S. (2005), 'ICT adoption in Italian manufacturing: firm-level evidence', Industrial and Corporate Change 14(2), 225–249.

Fernandes, A. M., Mattoo, A., Nguyen, H. & Schiffbauer, M. (2019), 'The internet and chinese exports in the pre-ali baba era', Journal of Development Economics 138, 57– 76.

Fogliatto, F. S., da Silveira, G. J. & Borenstein, D. (2012), 'The mass customization decade: An updated review of the literature', International Journal of Production Economics 138(1), 14–25.

Forgione, A. F. & Migliardo, C. (2023), 'Disrupting regional efficiency gaps via industry 4.0 firm investments', Industry and Innovation 30(1), 135–158.

Gal, P., Nicoletti, G., Renault, T., Sorbe, S. & Timiliotis, C. (2019), 'Digitalisation and productivity: In search of the holy grail – firm-level empirical evidence from EU countries', OECD Economics Department Working Papers 1533.

Koch, M., Manuylov, I. & Smolka, M. (2021), 'Robots and firms', The Economic Journal 131(638), 2553–2584.

Malerba, F. & Orsenigo, L. (1996), 'Schumpeterian patterns of innovation are technology-specific', Research Policy 25(3), 451–478.

Sanderson, L., Wright-McNaughton, G. & Yashiro, N. (2022), 'Does faster internet in- crease exports? evidence from New Zealand', OECD Economics Department Working Papers 1730.

Strange, R. & Zucchella, A. (2017), 'Industry 4.0, global value chains and international business', Multinational Business Review 25(3), 174–184.

Syverson, C. (2011), 'What determines productivity?', Journal of Economic Literature 49(2), 326–65.

Teruel, M., Coad, A., Domnick, C., Flachenecker, F., Harasztosi, P., Janiri, M. L. & Pal, R. (2022), 'The birth of new HGEs: internationalization through new digital technologies', The Journal of Technology Transfer 47(3), 804–845.

Wagner, J. (1995), 'Exports, firm size, and firm dynamics', Small Business Economics 7(1), 29–39.

Zolas, N., Kroff, Z., Brynjolfsson, E., McElheran, K., Beede, D. N., Buffington, C., Goldschlag, N., Foster, L. & Dinlersoz, E. (2020), 'Advanced technologies adoption and use by U.S. firms: Evidence from the annual business survey', National Bureau of Economic Research, Working Paper Series 28290.

Appendix A: Variables

Table A.1: Variables, measurement and source

Variables	Measurement	Source
Dependent Variables		
Export performance	log of 1 + sales in international markets per employee	SCIE
Digital technologies		
Robots	Indicator variable if the firm reports working with robots	IUTIC
Big Data	Indicator variable if the firm reports analysing and using big data	IUTIC
3D Printing	Indicator variable if the firm reports using 3D printing for any purposes	IUTIC
Machine Learning	Indicator variable if the firm reports using internally machine learning techniques	IUTIC
Artificial Intelligence	Indicator variable if the firm reports using or producing systems or devices that incorporate technologies, among others, text mining, computer vision, speech recognition, or natural language generation	IUTIC
Internet of Things	Indicator variable if the firm reports using interconnected devices or systems that can be monitored or remotely controlled via the internet	IUTIC
I4.0	Indicator variable if the firm reports adopting any digital technology related to Industry 4.0	IUTIC
Control variables		
Firm's size	Log of number of employees	SCIE
ICT Specialists	Indicator variable if the firm reports employees with ICT skills	IUTIC
ICT Training (for other employees)	Indicator variable if the firm reports as providing training for non-ICT specialists	IUTIC
Ultra-Fast Broadband (>= 100 Mibts/sec)	Indicator variable if the firm reports having a fixed internet connection speed for downloads equal or above 100 Mibts/sec	IUTIC
Cloud computing adopter	Indicator variable if the firm reports contracting and using cloud computing services	IUTIC

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