



Research article

E-commerce of Peruvian SMEs: Determinants of internet sales before and during COVID-19

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ABSTRACT

The COVID-19 pandemic accelerated the adoption of e-commerce among Peruvian small and medium enterprises (SMEs), prompting a sudden shift from traditional physical marketplaces to online sales. Before the pandemic, many businesses were beginning to adopt ICTs but only 8.1 % were selling their products and services online. The study aims to analyze the determinants of online sales in Peruvian SMEs in 2019, and the factors that contributed to the rise in online sales during the first year of the COVID-19 pandemic. The Peruvian National Enterprise Survey 2019 was used to evaluate the e-commerce adoption behavior of SMEs during 2019 and 2020. To analyze the determinants and factors, Heckman two step model was employed. The findings revealed that digital readiness was crucial for adopting online sales, but not significant for scaling sales during the pandemic; the rise in sales during the social lock-down period necessitated the implementation of a unique product delivery approach many times using own vehicle and bearing in mind informal competition. In essence, digital readiness played a critical role in enabling Peruvian SMEs to adopt online sales, but its impact was limited when it came to scaling sales during the pandemic. This research contributes to the existing literature by highlighting the unique challenges and opportunities faced by SMEs in a developing economy during a global crisis. The implication of this study highlights the need for CEOs at SMEs to prioritize digital readiness, as well as rebuild from the economic impacts of any crisis.

1. Introduction

The State of National Emergency (SEN) declaration enforced a quarantine to hinder the COVID-19 pandemic contagion by limiting people's movement. This action resulted in reduced production and labor adjustments [1,2]. On the other hand, marketing performance supported by technological development [3], service provision with an emphasis on digitalisation [4], particularly in conventional settings like factories, shopping centers, and physical markets [5,6] increased. Thus, the negative effects of the pandemic were swift and significant for businesses involved in transportation; however, Small and Medium Enterprises (SMEs) were the most

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severely and rapidly affected group [7]. Peru was among the first Latin American countries to implement this measure, significantly altering the business landscape from March 2020 - when mandatory social restriction was imposed [8]- until the end of the state of emergency in October 2022. Businesses had to adjust their marketing strategies to incorporate digital channels for promoting and selling their products, as well as facilitating transactions. However, high risks and lack of financing were significant challenges, especially for SMEs [9].

Several studies have been conducted to determine the factors responsible for the adoption of online shopping [10–15]. Ahmed and Sathish [11] conducted a meta-analysis on the determinant of online shopping adoption. These determinants which were termed as drivers of online shopping encompassed attitude, security, trust, experience, perceived usefulness, e-sustomer service, product involvement, privacy, convenience, hedonic motivation, amongst others [11]. Due to the pandemic, consumers had to adapt their purchasing and payment methods, particularly those who were previously excluded from digital commerce and had to acquaint themselves with virtual platforms, electronic banking, and payment cards [16]. It was observed that SMEs using digital platforms for commerce could gain competitive advantage, access new markets, and leverage resources, including intellectual property [17].

Preliminary results during the initial months of the quarantine revealed that, merely 22.7 % of companies were capable of running their operations entirely as 24.5 % of firms ceased their operations [18] which would be linked in part to disruptions in supply chains, lack of demand and difficulties in rotating capital [70]. Among the firms that continued to operate, 67.4 % observed reduced sales while 11.7 % encountered no sales [18]. Similar situations were apparent outside Peru, as demonstrated by Ref. [19] research on California, which highlights a 17 % decline in business sales for the second quarter of 2020 and an overwhelming 91 % loss for accommodation services. Interestingly, online sales sprouted by 180 % in California. Companies had to adapt their business model and adopt digital sales channels to maintain operations [20]. Studies have even shown that companies' investment in digital channels before the pandemic caused them to have less drop in sales during the pandemic [71]. It was even found that SMEs that implemented digitalisation increase their financial performance [72]. This process could present an opening for companies, particularly for those familiar with digital platforms like social networks, given their ability to facilitate knowledge acquisition, enhance organisational competitiveness, and improve the business trajectory [21].

It has been projected by PCMI that e-commerce in Latin America would exceed \$510 billion in 2023, with 27 % increase in 2023 surpassing 2022; and a compound annual growth rate (CAGR) of 23 % from 2023 to 2026 [22]. According to PCMI data, Peru is the fastest-growing e-commerce market in Latin America, haven been forecasted with a robust CAGR of 35 % between 2023 and 2026 [22]. Chevalier [23] remarked that Peru has gone through a remarkable e-commerce revolution, especially as a result of the surge in 2020 caused by the outbreak of the COVID-19 pandemic.

Key elements or components that define e-commerce in Peru and will propel its expansion and development to catch up to the turnover rates of the major Latin American economies were studied by Caycho-Vilchez et al., in 2021 [24]. According to their findings, the most sensitive variable was consumer electronics culture, followed by consumer distrust, consumer banking, and e-commerce application development to a lesser degree. Additionally, it was discovered that Peru's adoption of e-commerce has benefited from the COVID-19 epidemic [24].

In contrast to other nations, the progress of science and technology in Peru is still at an early stage, as evidenced by its 84th out of 166 ranking for frontier technologies in the UNCTAD 2022 report [25]. This could contribute to the restrictions on e-commerce in the country. Thus, the prevalence of digital servitization and the use of digital tools among SMEs was limited prior to the pandemic [26]. Despite the fact that 90 % of SMEs had access to internet services, according to SEN only 18.6 % made purchases through this channel and a mere 8.1 % had sales in 2019. On average, e-commerce constituted 31.6 % of companies' total sales. However, exclusively relying on online sales was a strategy adopted by only 3.5 % of firms, with 12.4 % realising less than 1 % of their total sales through this mode. Following nearly a year of implementing the SEN, 80.6 % of businesses confirmed an increase in levels of e-commerce, compared to the previous year's 48.1 %. Conversely, 28.6 % reported no change (for further details, refer to Annex 1).

Physical products constituted the majority of online orders (69.5 %), which were subsequently shipped physically. Following this were orders of online services which did not require shipping (26.1 %). This change is linked to commercial shifts, including the significant growth in social network use for B2B businesses during the pandemic [21].

To distinguish from the other studies reviewed, where the main objective is to determine the use of e-commerce and not its success, measured in terms of percentage increase in sales, especially in adverse contexts such as the COVID-19 pandemic. In this context, focusing on the first year of SEN application, the objectives of this study is to examine the factors that have led to a surge in online sales among Peruvian SMEs (Small and Medium- Sized Enterprises) during the first year of the COVID-19 pandemic in Peru. The motivation for this study arises from the need to understand the challenges and opportunities that Peruvian SMEs face in the e-commerce landscape, particularly during the COVID-19 pandemic. Furthermore, the research will provide answers to the following questions: 1) What determined the decision to conduct online sales in the period preceding the pandemic in 2019, and 2) what variables are associated with the rise in online sales during the first year of the pandemic, in 2020?

This research makes a significant contribution to the knowledge of how SMEs in upper middle-income countries adopted digital sales strategies, emphasizing their success during a period of unexpected shock like COVID-19. Understanding these decision-making processes can inform future strategies for resilience and digital transformation in similar contexts.

2. Prior work

2.1. SME and COVID-19

The presence of SMEs is linked to two distinct yet often interrelated occurrences. Firstly, they are viewed as a means of survival in

the context of limited employment opportunities. Secondly, they serve as a mechanism for promoting economic and social development [27]. In Peru, SMEs account for 99.5 % of formal companies and employ 59.2 % of the workforce [28]. However, despite their significant presence in the market, SMEs experience a high failure rate and struggle with limited resources and lack of access to financing [20]. These challenges make SMEs particularly susceptible to unanticipated crisis, such as the COVID-19 pandemic, highlighting their vulnerability in the economy.

The pre-pandemic economic conditions were characterised by a reduction in raw material prices [1]. Peru was among the countries with the highest growth and most promising outlook for the region, while also preserving stable currency [29]. This indicates a favourable business environment. However, the pandemic is a Black Swan event, which means it is an extremely rare and surprising event that causes a significant impact on the economy. According to Ref. [6], digitalisation occurs in the context of unforeseen events, such as the COVID-19 pandemic, as a transition from a favourable market to a challenging or volatile market. The favourable market offers investment and marketing opportunities, whilst the volatile one is dominated by precarious industries, a harsh business climate, intense competition, and a dearth of exploitable prospects.

In response to the COVID-19 pandemic, emergency measures were taken that resulted in the restriction of some traditional trade routes. Specifically, this affected physical locations such as markets and shopping centers, causing both suppliers and buyers to adapt [30]. highlighted three characteristics of the initial wave of the pandemic that distinguish it from other shocks: sudden emergence, sustained impact, and exogeneity. The reduction in consumer budgets, exacerbated by the “digital divides” and the lack of time and information to adapt, resulted in a significant decline in companies’ actual income [31].

In European nations and the United States, COVID-19 had a direct impact on self-employed individuals and small businesses, as researched by Ref. [32]. This resulted in supply chain disruptions, reduced demand, decreased operating hours, and alterations to the business model, leading to a higher incidence of business closures, decreased sales, and more significant layoffs. However, these companies also demonstrated heightened resilience and capacity for resource integration whilst identifying new opportunities amidst the COVID-19 crisis.

In Peru, the COVID-19 restrictions led to a surge in unemployment, income loss, and poverty [8]. Micro and small businesses were hit the hardest [20]. The pandemic affected all sectors, but had a particularly significant impact on hospitality and tourism, commerce, traditional cultural industries, and transportation [33].

2.2. Digitalisation and electronic commerce during COVID-19

According to Ref. [6], digitalisation is defined as the partial or complete transition of a company’s value chain activities and business models to digital platforms facilitated by emerging technologies. Electronic commerce, involving transactions over the Internet to establish exchange terms and sell goods or services that can be either sent offline or “digitized and sent online” [34], is an integral component of companies’ digitalisation strategies. Adopting technologies can be seen as a sequential process for small and medium-sized enterprises, as emphasized by Refs. [35,36]. Starting with basic tools, companies progress to creating a website to offer products. E-commerce is implemented, enabling customers to order and pay online, reducing costs and maximizing efficiency. Next, companies adopt Information and Communications Technologies (ICT) in internal processes, which aid supply chain management through e-business, culminating in an organisational transformation.

As [34] note, SMEs can benefit from e-commerce by lowering their expenses associated with entering new markets and by reducing distribution costs. Furthermore, e-commerce allows SMEs to expand their reach to a larger population of potential clients. According to Ref. [37], the adoption of the Internet as a distribution channel in Spanish B2C companies is influenced by the competitive environment, the type of product distributed, and the size of the organization. No evidence was found to suggest that the degree of internationalization or whether the company is local or foreign has an impact on adoption.

As [38] argues, four factors influence the decision to adopt electronic commerce: i) the technological context, including the perception of the technology’s benefits and acceptance, compatibility, and adoption costs; ii) the organizational context, encompassing technological readiness and infrastructure, technical acumen, and business size; iii) the environmental context, which addresses external factors such as relationships with customers, suppliers and competitors, as well as support for adoption from external entities; and iv) the individual context, which is particularly relevant for SMEs where either the manager or owner has a crucial role in decision-making. In the Indonesian context, factor analysis revealed that perceived benefits, technological readiness, innovation capacity amongst owners, owners’ IT capacity, and owners’ IT experience were the most significant factors.

Companies can adopt measures to digitise quickly, anticipating their future usefulness. Alternatively, they may go through a learning process during times of recession, where their survival is threatened and faced with the latent danger of failure. The only way out is to adopt greater digitalisation [6]. However, poor internet infrastructure in developing countries and rural areas poses additional challenges, making the process more complex and difficult.

During the COVID-19 pandemic, two factors significantly influenced the use of electronic commerce: the mandatory and extensive transition of consumers to online purchasing and the confinement aspect [30]. The authors found that Chinese companies with physical stores that adopted e-commerce strategies through third-party digital platforms showed greater resilience in sales and inventories. Companies that use their own platforms had a smaller, insignificant impact, except in regions with higher severity.

The constraints imposed by the current scenario served as a catalyst for the integration of digital technologies and platforms, thereby enabling remote work and online transactions [6]. At the organizational level, the COVID-19 pandemic necessitated the fast-tracking of digitalisation and electronic commerce processes. According to statistical evidence from countries like Mexico [39], SMEs shifted their sales to online channels. E-wallet transactions facilitated social distancing during the COVID-19 pandemic and aided in preventing the spread of the virus. Moreover [40], research indicates that the initial acceptance of electronic wallets was

significantly influenced by perceived severity, perceived susceptibility, and self-efficacy.

According to Ref. [41], a logit and probit model for the Spanish context showed that trust in online transactions (e-trust) is crucial for increasing the likelihood of using electronic commerce, alongside education, income, and digital skills. Recently [42], utilized the bivariate probit model to determine that the impact of digitalisation on firms is reliant on size and SMEs without research and development are motivated towards introducing new products.

Probit models, similar to logit models, can be used to explain the impact of explanatory variables on the dependent variable. For instance Ref. [43], found that the logit model estimates showed significant effects of four variables on increased payment cards use at point of sale due to fear of contagion and perception of new technologies as beneficial for social distancing, unlike probit model.

2.3. The Diffusion of Innovations Theory

This theory explains how new ideas, products, or technologies spread and are adopted by individuals and organizations within a social system [44]. The Diffusion of Innovations Theory was developed by Everett Rogers in 1962. It describes the spread of novel invention or idea through various stages of adoption amongst different groups of people (adopters) who participate in its use. The theory is used by marketers in the promotion of their goods and services. These adopters can be grouped into categories - the innovators, early adopters, early majority, late majority, and laggards. Accordingly, there are different stages of adoption. The theory aims to understand the process by which innovation diffuses and the factors influencing its adoption [45].

The theory consists of five stages of adoption [44]. These include-knowledge of the existence of an innovation (awareness); inquiry about the innovation (interest) as this would drive the adoption or rejection of such innovation; accessing the potential risks and rewards of such innovation (evaluation); initial use or testing the innovation on a small scale (trial); and continued use of the innovation (adoption).

2.4. Technology-Organization-Environment (TOE) framework

A widely used model in understanding the adoption of technological innovations is the TOE framework. The TOE framework consists of three main elements-technology, organization, and environment. The concept of technology, as regards the TOE framework entails the technological aspects of the innovation [46].

This framework aligns with the Diffusion of Innovations (DOI) theory, whereby Rogers established that individual traits and the organizational internal and external attributes were the most salient drivers of innovativeness. These elements correspond to the technology and organization contexts within the Technology-Organization-Environment (TOE) framework [46,47]. However, TOE goes further than DOI by including an additional critical component: the environment context. This context of the environment thus introduces constraints but equally opportunities that influence technological innovation [47].

The TOE framework improves Rogers' innovation diffusion theory by integration with the environmental context, and therefore, it can more suitably explain the diffusion of innovations within a firm. This added dimension offers insight into how external environmental factors impact the organization's adoption and implementation of new technologies [48]. TOE framework has a broad range of applications. It has been used in a number of studies to explain the adoption of e-business, electronic data interchange, inter-organization systems, amongst others [49].

In each study, the three elements of technology, organization, and environment have been shown to influence the way a firm identifies a need for, seeks out, and adopts new technology [47]. In each of the empirical studies testing the TOE framework, researchers have used somewhat different factors for the technological, organizational, and environmental contexts. Essentially, researchers have agreed with Tornatzky and Fleischer, 1990 that the three TOE contexts influence adoption, but these researchers have then assumed that for each specific technology or context that is being studied, there is a unique set of factors or measures. For example, in Ref. [50], the authors argue that "technology readiness" is one important factor that influences the adoption of e-business [47].

3. Methods

3.1. Data

The research employed a quantitative approach, drawing on data from the National Enterprise Survey (ENE) 2019, conducted by the National Institute of Statistics and Informatics (INEI) during the last quarter of 2020. The survey used a combination of sampling methods - "forced stratum" and "probabilistic, stratified, one stage, and independent" sampling. The first (forced stratum) ensured that the largest companies (top 80 % of sales) in each industry division (as classified by the ISIC rev.4) were included in the survey. The second method involved randomly selecting a representative sample from each industry division, with a focus on ensuring representation from all divisions. As a result, 13,330 formal companies were selected for the survey meeting the following criteria: developed economic activity in 2019, located within the national territory, and that had sales equal or greater than 50 UIT (UIT represents Tax Unit = 4200 soles; equivalent to about US\$ 60,000). The survey was administered virtually and it has a regional inference level, by company size and economic activity (ISIC rev. 4). The ENE allows the collection of information on company characteristics, managerial practices, use of ICTs, training, performance, productivity, among others allowed by CEOs.

Out of the entire sample, 6770 companies belong to the SMEs category. For the purpose of this study, SMEs are defined as companies with annual sales ranging from S/210 thousand to S/9.6 million (between US\$ 60,000 to US\$ 2,760,000) and employing no

more than 100 individuals, using similar criteria as [38]. In addition, the sampling is independent in each ISIC division, for this reason the probabilities of being selected are different in the sample. Thus, the expansion factor is considered when performing the calculations and econometric models.

This database makes it possible to characterize the company and determine key variables for the e-commerce adoption process and its determinants. A characteristic of this survey is that although the base period was 2019, due to the context and the need to have information on the possible effects of the first stages of COVID-19 and the SEN, a group of questions on the current situation were included. Regarding the 2019 period, questions were included to determine the size of the company, human resources, use of digital strategies, business management, use of ICTs and economic performance.

The survey included questions about the current business situation during the COVID-19 pandemic (conjectural questions). These questions were asked during the first wave of the pandemic in 2020 and focused on the results of e-commerce. [Supplementary Table 1](#) shows the list of variables used and the reference year for each of them.

3.2. Model

As shown in the literature, the TOE model explains the factors that influence the decision to adopt e-commerce. However, adoption does not ensure success, in other words, it is maintained and increases over time, especially in the context of black swan events such as the COVID-19 pandemic. Therefore, an extension of the model is necessary, adding a second stage where success is measured after adoption. [Fig. 1](#) shows the two-stage extension of the model. To the contexts described in the TOE model [26,27,51], a trust factor is added to ensure success, a key element in developing countries [52]. The database does not allow for measuring the degree of consumer trust, so logistics for product delivery is considered a proxy, as it increases the probability of successful delivery and thus generates more trust among customers.

As we will use the sample for the case of firms that already had some level of internet sales prior to the pandemic (2019), leaving aside those that did not, this takes away the randomness of the representative sample of firms, we are truncating the sample towards a specific population group. According to Ref. [53], this can lead to problems of selection bias. Therefore, a two-stage Heckman model is applied to alleviate the sample endogeneity problem [54]. This model is a two-stage least-squares estimation, where joint normality of the errors of both equations is assumed [73], this assumption implies that:

$$E(y_2 | x_1, y_1^* > 0) = x_2' \beta_2 + \sigma_{12} \lambda(x_1' \beta_1)$$

Where $\lambda(\cdot) = \varphi(\cdot) / \Phi(\cdot)$ represents the ratio of the Standard Normal Probability Density function and Cumulative Distribution Function, also known as the inverse Mills ratio (IMR).

Thus, in the first stage, a probit model is constructed to measure the decision to sell online before the pandemic (selection equation). From this equation, the inverse Mills ratio (IMR) is obtained and added in the second stage to correct for selection bias. The selection equation is defined as:

$$y_{1i} = x_{1i}' \beta_1 + \varepsilon_{1i} \dots \quad (1)$$

Where y_1 is a binary variable for firms selling online, x_1 are independent vector variables associated with y_1 , such as the size of the firm, approximated by the number of employees (a proxy for firm size), the experience and education of the founder, the location in the capital region, exporting status, the formal competition of the firm and its market concentration, measured by the Herfindahl-Hirschman Index (HHI). Additionally, six economic dummy variables were included as control variables, with services further divided into hotels and restaurants versus other services. The same model is regressed without the sectoral variables to test the robustness of the results.

In addition, it is considered in x_1 three digitalisation factor variables derived from principal component analysis (PCA) method.

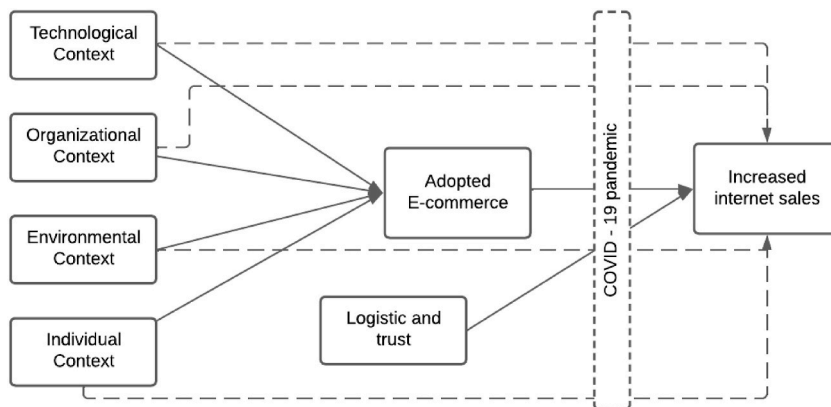


Fig. 1. Extended TOE model in COVID-19 pandemic context.

This approach allows for the consolidation of numerous digitalisation variables, a critical factor in e-commerce adoption. This study utilized ten variables, including: the utilization of digital platforms, social media presence, website ownership, promotion of products through digital channels, computer ownership, possession of a smartphone, online purchase behavior, reception of digitization training, identification of training requirements in digitization, and use of technological services.

The probit model will be utilized to model the data, and subsequently, the forecast of the model will be applied to derive the inverse Mills ratio ($\lambda(\mathbf{x}_1' \hat{\beta}_1)$) in Step 2. Step 2 is the outcome equation and is defined as:

$$y_{2i} = X_{2i}'\beta_2 + 12 (X_1' \hat{\beta}_1) + \varepsilon_2 \quad (2)$$

In this case, y_2 is a binary variable that takes a value of 1 if the internet sales company increased its volume during the first wave of COVID-19 in 2019. \mathbf{x}_2 represents the independent variables used in Step 1, excluding the primary economic sector due to its absence in the sample, and including informal competition, which was only assessed for 2020. Step 2 also included eight additional variables, namely: process digitization, digital marketing strategies, use of e-wallets, internet ownership, the use of ICT for sales processes, finance, and logistics. There are mainly the digitalisation variables utilized in the selection equation are grouped together and other variables related to the context and use of ICT are added. According to Ref. [35], this represents the adoption phase of the digitalisation process. Additionally, the Mills variable has been added ($\lambda(\cdot)$) to account for possible sample selection bias. Table 1 presents the primary descriptive statistics based on the model used.

To further analyze the data, we calculated the marginal effects (m) of each variable, which show the change in the probabilities of increasing internet sales when all other variables are held at their mean values. Additionally, we calculated odd ratios for step 2, which indicates change in odds of increasing internet sales when a unit change is made to an independent variable, while controlling all other variables. To avoid heteroscedasticity problems, regressions with robust standard errors are used in both steps. In addition, the variance inflation factor (VIF) of the explanatory variables is analyzed to identify collinearity problems.

3.3. Statistical estimation method

The statistical estimation method used for this study is the maximum likelihood estimation (MLE). Maximum likelihood estimation

Table 1
Descriptive statistics.

Variable	Definition	Step 1 (N = 6770)		Step 2 (N = 448)	
		Mean	SD	Mean	SD
Dependent variables					
ecommerce	Sells online	0.081	0.272		
y_ventas	Increase in online sales			0.481	0.500
technological context					
platformdig	digital platform	0.126	0.332	0.461	0.499
redessoc	social media	0.103	0.303	0.389	0.488
pweb	website	0.251	0.434	0.604	0.489
promdig	digital promotion	0.355	0.479	0.843	0.364
computadora	use of computer	0.894	0.307	0.996	0.067
smartph	use of smartphone	0.739	0.439	0.860	0.347
compras	online shopping	0.187	0.390	0.554	0.497
digproc	digitization of production processes			0.267	0.442
estrat	strategy of digital tools			0.591	0.492
bill	electronic wallets			0.084	0.278
tic_ventas	use of ICT in sales processes			0.440	0.496
tic_finanzas	use of ICT in finance processes			0.068	0.252
tic_logistic	use of ICT in logistics processes			0.200	0.400
internet	internet access			0.995	0.072
organizational context					
capa_dig	training in digital topics	0.106	0.308	0.244	0.429
ncap_dig	identified need for training	0.475	0.499	0.690	0.463
servtec	use of technological services	0.073	0.260	0.218	0.413
ltrab	logarithm of workers	2.032	0.999		
exporta	engaged in exports	0.052	0.222	0.156	0.363
environmental context					
compf	increase in formal competition	0.400	0.490		
hhi	Herfindahl-Hirschman Index (HHI)	0.123	0.172	0.149	0.222
mlocal	only produces for the local market	0.615	0.487	0.391	0.488
compi	increase in informal competition			0.574	0.495
Individual/managerial aspects					
cond_exper	manager experience	10.523	8.583	12.161	9.380
Logistical aspects/trust					
transport	owns/rents a vehicle			0.620	0.485
delivery	delivery strategy			0.339	0.473

is one of the most basic important statistical techniques for estimating a probability distribution's parameters. The technique involves maximizing a likelihood function so that the observed data turns out to be as probable as possible under the taken model [55,56]. In other words, MLE chooses those parameter values under which the observed data is best explained, hence being one of the powerful techniques of fitting data according to models. MLE is notable for its features such as consistency, efficiency and asymptotic normality.

4. Results

4.1. Determinants of the decision to sell online prior to the pandemic

The descriptive statistics presented in Table 1 illustrate the characterization of companies in the selected variables for this model, with a sample size of 6770 SMEs and taking into account the expansion factor. Supplementary Table 2 shows the results of the factor analysis conducted through the principal components analysis method, showcasing the rotation of the factors. After performing calculations using the varimax option and verifying data adequacy through Kaiser-Meyer-Olkin ($KMO = 0.655$), we grouped the following into matrix F: i) Factor 1: digital platform usage; ii) Factor 2: hardware ownership and purchasing channels; iii) Factor 3: skill development for digitization. Step 1 will use three variables derived from these factors.

The initial model examined is linked to the choice of SMEs to conduct online sales in 2019, prior to the occurrence of the COVID-19 event and the resulting restrictions. The findings for this model are indicated in Table 2. The results show a slight significance in the reduction of the likelihood of SMEs engaging in internet sales with business size, as measured by the logarithm of personnel count. Similarly, to a lesser extent, the manager's tenure in the company, measured in years, also impacts the adoption of electronic sales channels.

There is a strong and statistically significant link between the size and structure of the markets in which a firm operates. This link is even stronger when the firm engages in international trade, specifically by exporting its products, facing high levels of formal competition in its primary product market, and possessing greater market power, as measured by the HH index. Conversely, the likelihood of success declines when the firm only focuses on local markets.

Regarding economic sectors, we used the manufacturing industry as a reference, the primary sector and construction show a lower likelihood of conducting online sales. If the aforementioned sectoral variables are excluded from the model, as shown in columns 2 and 4 of Supplementary Table 3, the variables retain similar values, except that the HH index is no longer significant. Analysis of the correlation between these variables reveals a strong association between the sectors and the HH index. This suggests that market power is significant in specific sectors.

In terms of the three variables related to digitalisation, the three factors were positively and significantly related, with the highest incidence being the possession of hardware such as computers or smartphones and making purchases online. Next in importance were

Table 2
Estimated Results of Online Sales, 2019 (Selection equation).

Variables	(1) coefficient	(2) margins effects	(3) coefficient	(4) margins effects
technological context				
factor1	0.403*** (0.047)	0.044*** (0.005)	0.392*** (0.050)	0.044*** (0.005)
factor2	0.492*** (0.087)	0.053*** (0.011)	0.448*** (0.087)	0.050*** (0.010)
organizational context				
factor3	0.290*** (0.057)	0.031*** (0.006)	0.287*** (0.059)	0.032*** (0.007)
Ltrab	−0.151** (0.077)	−0.016* (0.009)	−0.180** (0.072)	−0.020** (0.008)
Exporta	0.401* (0.206)	0.043** (0.021)	0.404* (0.215)	0.045* (0.023)
environmental context				
Compf	0.262* (0.146)	0.028* (0.016)	0.258* (0.147)	0.029* (0.017)
Hhi	0.892** (0.355)	0.096*** (0.037)	0.281 (0.323)	0.031 (0.035)
Mlocal	−0.321** (0.158)	−0.035* (0.018)	−0.342** (0.160)	−0.038* (0.019)
managerial aspects				
cond_exper	0.009* (0.00542)	0.001* (0.000596)	0.011** (0.00506)	0.001** (0.000570)
Sector control	YES	YES	NO	NO
Constant	−1.853*** (0.239)		−1.485*** (0.248)	
Pseudo R2	0.287		0.262	
Observations	6770	6770	6770	6770

Standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

the use of digital channels for processes, digital marketing via social networks and websites, and skill development for digitization training. To test whether these variables jointly influenced the probability of making online sales, prior to COVID-19, we conducted a joint significance test (F-test) where the null hypothesis was that all variable coefficients equal zero. The null hypothesis was rejected, demonstrating a significant joint influence of the digitization process. This was shown as well in Fig. 1 of the Supplementary Material.

4.2. Determinants of the decision to sell on the internet during pandemic

After performing the initial estimation, we estimated models 2 and 3, differing only in the type of estimation performed: probit and logit, respectively. The descriptive statistics for the sample of 448 companies are presented in Table 1, while estimated results are shown in Table 3. Columns 1 and 2 represent the model with sectoral controls, while columns 3 to 5 correspond to the model without controls. We analyzed the coefficient sign and marginal effects. The logit model's marginal effects are shown because they are similar to those of the other model. Furthermore, we assessed the odds ratios.

Before running the regression analysis, a factor analysis of the digitalisation variables was conducted for all 448 companies using the same methodology, and criteria as in model 1. Additional variables, based on current trends, were also included in the analysis. The results of this analysis are presented in Supplementary Table 3, and the Kaiser-Meyer-Olkin test of data adequacy ($KMO = 0.642$) was performed. As a result, four digitalisation-related variables were identified: factor 1- digital platforms, factor 2- information and communication technologies (ICTs), factor 3- digital strategies and marketing, and factor 4- hardware and digital channels. However, factor 1 was excluded due to its high correlation with the IMR, and high multicollinearity in the model.

Notably, the findings suggest that possessing or leasing a vehicle, as well as utilizing delivery services during the 2020 period, were crucial factors in the improved performance of e-commerce. The survey indicates that most products and services are physically delivered. Although it is unclear whether the acquisition was influenced by COVID-19 or pre-existing circumstances, a strong correlation can be inferred between this factor and the surge in online sales during the pandemic.

A significant correlation was detected between the surge in online sales in 2020, and the perceived rise in informal competition during the previous year (2019), related to the primary product or service offered by the MSEs, as shown in Fig. 1 of the Supplementary Material. The HHI index showed significance, although with a negative value, indicating that as market concentration increases, the probability of e-commerce success decreases. This study revealed that firms strive for competitive advantages over new entrants in the business sector, and e-commerce emerges as a vital marketing channel for generating better sales performance.

Table 3

Estimated results of the increase in e-commerce during the first year of COVID-19 (Outcome equation).

Variables	(1) coefficient	(2) margins effects	(3) coefficient	(4) margins effects
technological context				
fac2	0.031 (0.113)	0.009 (0.032)	0.025 (0.112)	0.007 (0.032)
fac3	−0.084 (0.124)	−0.024 (0.035)	−0.087 (0.123)	−0.025 (0.035)
fac4	−0.106 (0.107)	−0.030 (0.030)	−0.096 (0.105)	−0.028 (0.030)
organizational context				
experta	−0.399 (0.358)	−0.114 (0.103)	−0.452 (0.357)	−0.130 (0.104)
enviromental context				
Hhi	−0.881* (0.510)	−0.252* (0.142)	−0.885* (0.509)	−0.255* (0.143)
mlocal	0.142 (0.245)	0.041 (0.070)	0.131 (0.243)	0.038 (0.070)
compi	0.675*** (0.236)	0.193*** (0.063)	0.690*** (0.234)	0.198*** (0.062)
managerial aspects				
cond_exper	−0.003 (0.011)	−0.001 (0.003)	−0.002 (0.010)	−0.001 (0.003)
logistics/trust aspects				
transport	1.110*** (0.236)	0.317*** (0.055)	1.119*** (0.235)	0.322*** (0.055)
delivery	0.759*** (0.248)	0.217*** (0.065)	0.767*** (0.247)	0.221*** (0.065)
imills	−0.494** (0.237)	−0.141** (0.065)	−0.470** (0.228)	−0.135** (0.063)
Sector control				
Constant	YES −0.544 (0.459)	YES	NO −0.607 (0.447)	NO
Pseudo R2	0.2749		0.2696	
Observations	448	448	448	448

Standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Having reliable transportation and delivery methods, whether owned or leased, is essential for distributing products and services, as well as ensuring prompt delivery to customers' homes. Furthermore, informal competition has increased compared to the previous year, prompting the company's digital transformation. This transformation aims to expand its customer base, and overcome mobilization restrictions, emphasizing its significant importance. Based on the odds ratios of these four factors, specifically the ownership or rental of a vehicle during the COVID-19 pandemic, the likelihood of e-commerce sales in 2020 is over 6 times higher for those with mobility options relative to those who lack such means.

Our analysis did not reveal any significant correlations between various business size variables, including workforce, sales volume, value added, and exports, and internet sales performance in 2020. Moreover, the economic sector did not significantly influence internet sales performance, with the exception of the commerce sector, and digitalisation factors did not appear to play a significant role. Conversely, the insignificant result of the inverse Mills ratio tests raises doubt selection bias.

We conducted an F test for joint significance in the last two models, which allowed us to reject the null hypothesis of zero variable coefficients. Thus, we confirmed the consistency of both models. Similarly, tests were conducted for the variables related to digitalisation and logistics, with non-significant results for the former and significant results for the latter. Finally, a multicollinearity test (Variance Inflation Factor, VIF) was performed, with all cases resulting in values less than 5 (see [Supplementary Table 3](#)).

4.3. Model robustness

Additionally, two regressions were performed to verify the consistency of the results. The first corresponds to a probit model, on the probability of increasing online sales or not, which is essentially equation (2) without the inverse Mills ratio. This model directly measures the effect of the explanatory variables on the extent of selling online, without taking into account possible selection bias. The second equation uses a variant of the Heckman model, performing both stages simultaneously using maximum likelihood. In this case, it assumes that the error terms of both equations (1) and (2) are correlated with each other, this correlation being represented by the rho term (ρ) [73]. The results show no significant differences from those in column 1 of [Table 2](#). [Table 4](#) highlights the significant variables of transportation and delivery. The Heckman model reveals a significant rho value, confirming selection bias, which the model accounts for.

Additionally, to mitigate potential endogeneity in the model, as there may be factors that influence both the use of transportation or delivery services and the outcome of e-commerce, we conducted an additional comparison using Propensity Score Matching (PSM), similar to the approach taken by Ref. [54]. The objective of this strategy is to group firms with similar characteristics on observable variables with the difference that one group adopted strategies of use of transportation or delivery services and the other group did not, based on the estimation of the probability of using such strategies located within a common support zone [74]. We tested the average treatment effect (ATT) between those who use transportation or delivery services and those who do not, but are similar in observable variables. We employed the nearest neighbor matching, considering one neighbor without replacement, on a specific set of variables to estimate the ATT. [Table 4](#) shows the difference between the group that uses these services and the group that does not, with both cases being significant.

5. Discussion

5.1. On the determinants of the decision to make internet sales in the run-up to the pandemic (2019)

As indicated in the literature regarding the determinants of e-commerce adoption by firms (TOE model), all variables related to technological, organizational, environmental, and individual contexts were found to be relevant in stage 1.

Companies with smaller workforces have a greater tendency to sell online, potentially due to the increased innovation of SMEs as a result of lower internal bureaucratic barriers to implementing new ideas [57]. This may make it easier for SMEs to adopt modern business strategies, including e-commerce. Markets with increased competition face greater pressure and at risk losing demand. To counteract this, they adopt defensive innovation strategies, often using the internet as a sales channel.

Market expansion beyond localities, either regionally or internationally, is linked to adopting internet sales. Although causality may be bidirectional, the findings of this study aligns with [34], who highlight the benefit of e-commerce in reducing distribution costs and providing market access. While it may be a concurrent strategy, the internet undoubtedly enables e-commerce.

The significance of digitization-related factors aligns with Martin works' argument on the sequentiality and complementarity of electronic media use in digitization [35,36]. Furthermore, technological readiness is a crucial determinant regarding the adoption of

Table 4
Robustness test.

Variables	Probit	Simultaneous Heckman	PSM
<i>transport</i>	1.149*** (0.248)	1.030*** (0.238)	0.087* (0.053)
<i>delivery</i>	0.785*** (0.246)	0.707*** (0.230)	0.180*** (0.230)
<i>Athrho</i>		−0.453** (0.207)	

e-commerce [38]. Similarly, ownership of hardware and online shopping channels in 2019 shows a positive correlation with internet sales. This suggests that companies may be closing their technological gaps in response to market demands [58] and the increasing confidence in e-commerce transactions [41].

5.2. On the variables associated with the increase in internet sales during the first year of the pandemic, 2020

The COVID-19 pandemic's economic effects on agents, particularly small Peruvian firms, were an unforeseen shock. Similar outcomes were observed in various regions, such as California, where [19] found direct correlations between sales losses and COVID-19 cases per capita. The findings imply that the economic decline was influenced by both local enforcement and behavioral compliance with public health closure restrictions, as well as voluntary behavioral responses of the local population to COVID-19.

In response, firms increased their use of digital channels to sell their goods and services. The apprehended efficacy of 617 users of electronic commerce platforms in Vietnam suggests that the pandemic had significant impact on their perception of these platforms. The pandemic increased the perceived effectiveness of these platforms for economic gains. The perceived effectiveness had a potent impact on sustainable consumption [59]. Furthermore [60], found that companies with social networks, communication platforms, online contingency plans, and ICT managed COVID-19 more effectively. A survey of 364 California farmers who sell directly to market found that online sales and marketing helped them access markets during the pandemic, particularly for farms with higher revenues [61].

A key finding is that firms with their own transportation units saw an increase in online sales. This highlights the importance of delivery approaches. While it is not mandatory for companies to possess transportation for deliveries due to the possibility of outsourcing this process to a specialized company, having a means of transportation could significantly contribute to the success of their operations. Trust is a crucial factor in this success, as revealed by Ref. [41], who identify trust as an essential element for the effective implementation of e-commerce. In China [30], found that trust is a key factor in adopting third-party e-commerce.

This difference with the Chinese case can be explained by the fact that before the pandemic, the use of large e-commerce platforms such as Ali Baba had been more pervasive among Chinese consumers, so that in the face of COVID-19 restrictions it was more natural to expand consumption through this channel, while in Peru, where e-commerce penetration was still low, trust was more rooted in traditional channels and face-to-face commerce. Therefore, it was more reliable to go digital only if delivery was assured by the company itself.

Table 5
Comparison of variables or results of interest from this study with other related studies.

Variable (or result)	This study	Other studies	References
Technological Context	The use of digital platforms, possession of hardware and digital strategies are relevant to adopt internet sales (E1). However, they had no influence on the increase in internet sales (E2).	Study in China between 2019 and 2022 reveals that foreign platforms were more successful in searching for international markets to increase their sales, however some require direct interaction. Regarding marketing and digital strategy, a study carried out in Europe suggests that SMEs have greater potential to achieve better positive results between digital marketing strategies and sales	[40] [42] [38]
- Use of digital platform - Hardware and sales channels - Use of ICTs - Marketing and digital strategy			
Organizational Context	Digitalisation training, export and export skills had a positive impact on the decision to sell online. Size (measured in workers) had a negative impact (E1). There was no effect on his success post-COVID (E2)	A study carried out in Australia during the Covid-19 period shows that SMEs have better results with investment in technologies and development of capabilities in their staff; Thus, in a study carried out for Chinese companies, the digitalisation of SMEs facilitated their expansion potential in the foreign market.	[65] [66]
- Development of digitalisation skills. - Size Export			
Environmental Context	The scope variable (local market) had a negative impact, while greater concentration and the presence of formal competition had a positive effect (E1). While the increase in sales had an effect on informal competition (E2)	A study carried out in businesses in Latin America shows that formal SMEs had better favourable results for survival and development given that they had greater possibilities of accessing state support such as the "Reactiva" program in Peru.	[34]
- Formal competition - HHI - Local scope only - Informal competition			
Individual Context	The experience of the company manager (in years) had an effect on the decision to sell online (E1), but not on its subsequent increase (E2).	A study carried out in SMEs in China shows that Managers with experience in Information Technology have direct influence in the implementation of digital transformation in the company, which is related to online sales	[67]
- Manager experience			
Logistic and trust	Having the availability of a means of transportation and a delivery strategy had a significant effect on the increase in online sales	A study carried out with 400 consumers in Turkey indicates that "delivery speed" is the most desired attribute in electronic commerce. Regarding the delivery strategy, direct delivery is considered limited, so they propose a flexible delivery strategy to better meet demand	[59] [29]
- Transport - Delivery			

Regarding digitization [62], findings demonstrate that ICTs were adopted in SMEs in Germany based on rational dimensions (organizational, environmental, and technological characteristics) as well as their interrelation and the specific possibilities and limitations of the ICTs. ICT solutions like video conferencing have effectively addressed physical distancing in the short and medium term. However, more advanced technologies like virtual reality are becoming increasingly important. This importance is particularly evident in the long term, where virtual reality is expected to play a significant role. Evaluating ICT use for remote communication and collaboration must be done objectively, as it affects both professionals and consumers. Adequate analysis and objectivity can help identify ICT opportunities and challenges, leading to informed decisions. Therefore, based on our findings from Peruvian companies with e-commerce and videoconferencing capabilities, we recommended following the European experience and investing in augmented reality and virtual reality technologies. Although these technologies were not included in the survey, they are the next logical step in the evolution of digital solution.

On the contrary [63], discovered that during the COVID-19 pandemic, SMEs in Italy experienced most of the decline in profits and equity erosion concentrated in the Manufacturing and Wholesale Trade sectors. The Construction and Business Services sectors were also affected, although to a lesser extent. Notably, these sectors are also the top four by employment numbers. However, the Peruvian case study found no significant sectoral differences.

5.3. Comparison before and during pandemic

It is worth noting that the state of national emergency was a unique period marked by mandatory social immobilization, during which companies faced significant restrictions on production and marketing. Therefore, for companies to be able to expand their online sales, beyond the digitization process, which in some ways they had already started, it was vital to have the resources to ensure the provision of goods or services to the customer. Our findings support Alwan's conclusion that expanding supply chains for e-commerce is crucial for market growth [5]. Moreover, informal competition and use of own vehicle reveals some survivor strategies in accordance to the proposal novel decision-making environment in COVID-19 [64].

This issue can also be examined from the perspective of demand. Fernandez's study [41] emphasizes that for customers in Spain, trust is a critical factor in making online purchases. Considering that these firms have already embraced various forms of e-commerce to a certain degree, they have developed expertise in international expansion and product delivery. Ensuring direct delivery of products instead of through third parties may encourage customers to choose companies that offer direct delivery over those that do not.

Table 5 highlights a comparative perspective, showing how different contexts influenced online sales outcomes. For instance, while digitalisation strategies were impactful in our study, related studies also note the critical role of flexible delivery and managerial experience in e-commerce success.

5.4. Implication of the results

This establishes the role of innovation in SMEs: while the propensity to sell online is higher in businesses with smaller workforces, internal bureaucratic barriers are low in SMEs. Therefore, new ideas are quickly implemented, making them more agile and adaptive to modern business strategies—in this case, e-commerce. It means that the policies and mechanisms of support targeting further reducing bureaucratic hurdles might provide better competitiveness for SMEs through innovative practices and the adoption of technology. Therefore, in these highly competitive markets, there is a higher chance of adopting e-commerce and other online technologies in different ways as part of their various strategic defensive innovation strategies to ensure that they maintain their existing market share and customers. This could, therefore, imply that competitive pressures have a bearing on the adoption of technology, consequently leading to further innovation by firms. Companies in very competitive environments may consider options like e-commerce and other online tools for additional avenues about their sustainable market presence and growth.

This expansion of markets accompanies the adoption of Internet sales and underlines the critical role e-commerce can play in reaching wider audiences whether regional or international, expansion through the Internet reduces distribution costs and increases access to broader markets. Results confirm what the literature suggested—improved efficiency and reach advantages through e-commerce. From that perspective, investing in a robust infrastructure for e-commerce might be a strategic necessity for firms interested in expanding beyond local markets. What is incredibly possible, however, is the causality of both market expansion and adoption of Internet sales. This would suggest that although firms may use e-commerce to support growth, the ability to sell online might itself be one of the actual catalysts for expansion. Further, this supports the need for e-commerce integration into strategic planning on e-growth. Firms should not adopt e-commerce as a reaction to market conditions but engage in it as a proactive action for driving expansion and innovation.

These implications stress the need to bring innovations in culture at the SME level, channel competitive pressures toward commitment to technology diffusion, and expand market reach without compromising a strategic approach toward opening up to e-commerce. In this regard, policymakers and business leaders should, therefore pay much greater attention to cutting red tape, incentives for competitive innovations, and building actual e-commerce infrastructure if growth pickups are competitive.

5.5. Limitations

Some limitations of the study pertain to the features of the database, as it relies solely on CEOs permission and self-reported data with no means for external verification. Also, the study only examines companies that report sales exceeding 50 UIT during the specific

year surveyed. Furthermore, the impact of e-commerce on companies that reported no online purchases or sales in 2019 cannot be measured due to database limitations.

However, the database constraints limited the analysis to the area explored. More specifically, when it comes to youth entrepreneurship, individuals in their youth have limited expertise and prioritize seeking employment over self-employment. Changes in economic activities during a pandemic necessitate empirical investigation of the damage suffered from specific activity reductions among vulnerable labor market demographics, such as youth populations (e.g., as explored by Ref. [68]). Policy recommendations are proposed to mitigate potential rates of economic inactivity among young people during pandemics.

The study's failure to consider the user as a variable limits the analysis of objective 2. This is an additional area of concern. As a specific example, in Thailand [69], found that 11 % of individuals experienced a reduction in income of less than 25 %, while 12 % experienced a reduction of between 25 % and 50 %.

Overall, our results could serve as a basis for further research involving SMEs that experienced sharp declines in activity, business sentiment, and expectations early in the pandemic [62].

6. Conclusions

The research conducted during the COVID-19 pandemic highlights the severe impact of unexpected shocks on SMEs in Peru, which constitute 99.5 % of the country's businesses. This study distinguishes itself from earlier research by focusing specifically on the Peruvian context during the pandemic, offering a unique perspective on how SMEs were forced to adapt to the mandatory lockdown and the rapid shift to online sales. Unlike prior studies that primarily addressed general business resilience or the broad adoption of e-commerce, this research delves into the specific challenges and outcomes faced by Peruvian SMEs, providing a detailed analysis of their digital readiness and the role of e-commerce strategies.

The article contributes to the field by enhancing the understanding of how SMEs can navigate sudden economic disruptions through digital transformation. This brings to light the significance of the existence of pre-existing digital infrastructure and strategies, where businesses that had already taken up online sales before the pandemic have seen lucrative outcomes. Further, the research points out several direct delivery services that are important for consumer trust in a period of sales disruptions. This has important implications for policymakers and business leaders working to ensure increased resilience across SMEs, particularly to future shocks. This research study will be useful in devising strategies concerning how to cushion the effect of informal markets in strengthening the formal digital economy.

However, the study has several limitations, some of which pertain to the features of the database, as it relies solely on self-reported data with no means for external verification. This constraint limited the analysis to the area explored. Also, the study only examines companies that report sales exceeding 50 UIT during the specific year surveyed. Furthermore, the impact of e-commerce on companies that reported no online purchases or sales in 2019 cannot be measured due to database limitations. Furthermore, the failure of the study to consider the user as a variable limits the analysis of objective 2, which is an additional area of concern.

Future research could investigate the long-term effects of the State of National Emergency (SEN) and the pandemic on:

E-commerce, including comparisons with other regions and further exploration of specific determinants of internet sales. Understanding the sustained impact of the pandemic on e-commerce adoption and sales performance among SMEs in different regions will help elucidate the long-term effects of the pandemic on e-commerce both within and between regions.

In terms of infrastructure, Mugruza's work, which builds upon previous research on ICT and productivity, indicates gradual shifts in South America that impact the science, technology, and technological innovation system [75]. The advent of e-commerce has introduced new considerations in decision-making processes, both at the individual and infrastructural levels, due to the pandemic. Regional changes within Peru and across South America are also subject to debate and have implications for the future, particularly in the field of education, where legislation now permits 100 % virtual learning [76].

Additionally, future studies could focus on e-commerce strategies among SMEs, utilizing neuroimaging methods such as electroencephalography (EEG) and functional Magnetic Resonance Imaging (fMRI) to explore the cognitive processes involved in decision-making during digital transitions is yet to be done [77]. To the authors' knowledge, there are currently few studies focusing on CEOs in this context. This research could extend Katsaros's work on how decision-makers and CEOs process information [78], as well as the aging process [79], and Lashitew's work on how strategic choices regarding e-commerce and digital innovation are made [80]. This would provide a deeper understanding of the mental and emotional factors at play.

Finally, analyzing the impact of informal competition on digital transformation is crucial. Investigating how the presence of informal competitors influences SMEs' digital transformation efforts [25,53] can help develop strategies to mitigate the impact of informal markets and strengthen the formal digital economy, such as improving public data openness, as explored in recent work by Chen and Zhang [81].

CRedit authorship contribution statement

Miguel Angel Ortiz-Chávez: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **José Enrique Mendoza-Pumapillo:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Conceptualization. **Josue Otoniel Dilas-Jiménez:** Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition. **Carlos Andrés Mugruza-Vassallo:** Writing – review & editing, Writing – original draft, Supervision, Software, Project administration, Methodology, Investigation, Data curation, Conceptualization.

Data availability statement

Data preparation and econometric models were executed using Stata 16, available at https://github.com/MAORTIZCH/ecommerce_sme.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.heliyon.2024.e40331>.

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