



On the Direct and Indirect Effects of ICT on SMEs Export Performance: Evidence from Colombian Manufacturing

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Abstract

The objective of this research is to investigate the effect of ICT on the performance of Colombian manufacturing SMEs in export markets. In doing so, we explore the direct effect of ICT on exports and propose a new indirect effect that operates through imports: purchasing foreign intermediates incentivise ICT use, and ICT experience on imports exerts a positive impact on exports. To perform our empirical analysis, we estimate a dynamic generalised linear model (GLM) that accounts for the fact that export intensity is a proportion and corrects for sample selection. The dataset we use is the result of merging three databases: the Annual Manufacturing Survey (EAM); the Innovation and Technological Development Survey (EDIT), and the Annual ICT Manufacturing Survey (EAM-TIC), published by the National Administrative Department of Statistics (DANE) in six waves since 2013 to 2018. Our main results uncover that the impacts of different ICT components on export intensity are always positive (direct effect). Further, there is also evidence that previous experience in ICT use on import activity affects the firm's current export performance (indirect effect). Other results show persistence in export performance or self-selection to continue exporting, among others.

Keywords ICT · Exports · Imports · Sunk costs · Trade · Emerging economies · Empirical Analysis

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Introduction

Information and communications technologies (ICT) include a diverse mixture of technological tools that ease communication among people, institutions, governments, and firms. ICT contribute to *creative destruction* (Schumpeter, 1942; Soskice, 2022), since they establish new social orders that modify how people interact, for instance, through *e-mail* or *e-games*, how government or education institutions use them (*e-governance*, *e-learning*, *e-competences*), or how firms carry out production routines, import raw materials, or export final goods by using the *Internet*, *websites*, *e-marketing*, or *e-commerce* (Oliveira et al., 2020; Pezderka et al., 2012; Eden and Gaggli, 2014; Terzi, 2011; Xing, 2018).

In the era of globalisation, using ICT in export activities is crucial for firms because it allows them to improve competitiveness in local and foreign markets. This is so because ICT stimulate economies of scale, since they reduce operative, transport, and information costs, or even those related to bureaucratic red tape (Osterlof, 2011). Moreover, ICT expedite the introduction of new knowledge or R&D activities, increase the firms' demand, and improve the quality of customer service (Koutroumpis, et al., 2020; Jameel, et al., 2017; Grazzi et al., 2016, among others).

The effect of ICT on firms' exports activity has been explored mainly in developed countries over the past two decades (Caselli and Coleman, 2001; Onyeiwu, 2002; Ueki, 2005; Wallsten, 2005; Clarke and Wallsten, 2006; Hagsten and Kotnik, 2017; Añón Higón and Bonvin, 2022, among others), while in emerging economies, the interest in studying this linkage is more recent and scarcer (Ahmad et al., 2011; Makanyeza and Ndlovu, 2016; Mathews and Bianchi, 2010, among few others).

In general, the empirical research addressing the firm's export decision to enter in export markets is known as *propensity process*. Nevertheless, the ICT influence on firm's performance in export markets, or *intensity process*, has barely been examined and, in the case of emerging economies, still remains unexplored. The scarce literature in these countries is possibly due to the difficult to access ICT by small- and medium-sized enterprises (SMEs) beyond the Internet or websites. This problem is worsened by the high percentage of these firms in manufacturing industries (92% in the case of Colombia and 99% in Latin America), together with their capacity issues, financial constraints, and insufficient official support.

Regardless of the country analysed, the ICT-export link is explained in general by a well-defined channel that captures the direct effect on export participation. Firms use mainly generic ICT to establish business relations with clients, consumers, or providers (Ahmed and Ridzuan, 2013; Yushkova, 2014; Grazzi et al., 2016; Hagsten, 2015; Hagsten and Kotnik, 2017). For instance, the use of extranet contributes to the sharing of firm's inner information with customers, or Internet usage decreases transaction costs. Further, having website reduces uncertainty between traders, and the high use of more advanced ICT, such as *e-commerce*, allows more fluid transactions (Racela & Thoumrungroje, 2020; Ozcan, 2018; Laudon et al., 2016). However,

the ICT-export link may not be so explicit, since other factors such as firm's productivity may contribute indirectly in this relationship (Añón Higón and Bonvin, 2022).

In this work, we propose a new indirect channel for emerging economies that operates through the previous ICT experience on import activity that may have an effect on current export firms' performance. This might be justified because importing is a more frequent activity than exporting, at least for small firms in emerging economies, as Colombia (Lechuga Cardozo et al., 2017). Besides, in the industrial and commercial free zones in Colombia, construction materials and equipment, raw materials and inputs, and the machinery for manufacturing plants can be imported duty free (Rosero, 2014). Moreover, in general, it is easier to import than to export since purchasing abroad does not depend on the legal regulations of the trader country. All in all, we claim that importing requires the importer to contact providers and/or suppliers or share information among traders. Since ICT is the cheapest technology to communicate, a firm's extensive usage of these tools will allow it to gain knowledge and/or experience in its management, which might positively affect firm's current export performance.

Although access to ICT remains difficult in emerging economies, we consider that ICT have gradually allowed firms to engage in international trade (Osorio-Gallego, et al., 2016). Specifically, in the case of Colombian manufacturing, see Gómez Sánchez (2020), there is evidence on a strong link between firms' internationalisation strategies and the usage of different types of ICT. According to this study, 72.4% of firms that do not import or export use electronic devices (PCs, smartphones, and tablets), but this figure is higher for firms that only export (87.1%) and even larger for firms that import and export simultaneously (94.7%). As this pattern is replicated for other ICT analysed, we can conclude that the more connected firms are to international trade, the greater the use of ICT. Furthermore, this trend has been reinforced by the creation of the Ministry of Information Technologies and Communications in 2009 and the Ministry of Science, Technology and Innovation in 2022 that have the aim to promote ICT at different levels, including SMEs, in Colombian manufacturing (Gómez Sánchez, 2020).

The objective of this work is to examine ICT effects on the export performance of Colombian manufacturing SMEs. In doing so, we focus on direct effects of ICT on export performance and in a new indirect channel that operates from imports to exports. For this purpose, we merge three databases at the firm level, namely, the Annual Manufacturing Survey (EAM), the Technological Development and Innovation Survey (EDIT), and the Annual ICT Manufacturing Survey (EAM-TIC). All these are published by the National Administrative Department of Statistics (DANE) covering six waves, from 2013 to 2018.¹ We estimate a dynamic generalised linear model (GLM) that considers that the export intensity is a proportion (i.e., firm's foreign sales over total sales). Further, we will also account for sample selection bias by including in our specification the inverse Mills ratio (Hagsten and Kotnik, 2017; Añón Higón and Bonvin, 2022).

¹ We cannot consider a longer analysis period because the first wave of the EAM-ICT survey was published in 2013.

Our contributions to the empirical literature are manifold. Firstly, we introduce a new indirect channel to explain the ICT-export link that operates from imports to exports through the cumulative experience obtained in the previous ICT use in import activities. Secondly, we contribute to the scarce empirical literature on this topic, mostly in emerging economies as Colombia, by accounting for several issues such as sunk cost/persistence, self-selection/continuation process, or dealing with the possible correlation between unobserved firm's heterogeneity and past export decisions. Thirdly, we consider that the export propensity and intensity processes could be related, so we explore the possible non-random sample selection bias. Fourthly, we proxied firm's productivity through TFP by using the procedure proposed by Wooldridge (2010) and consider an endogenous Markov process for the law of motion of productivity including past ICT experience. Fifthly, to properly capture a firm's communication capabilities, we consider seven ICT measures (beyond the Internet and websites). Sixthly, since ICT use is highly related within firms, we estimate the empirical model by taking five ICT proxies one-by-one to avoid multicollinearity, but as this decision could induce bias by misspecification of models, we also include two proxies that consider all ICT together, in the form of total ICT investments and an ICT index constructed using Cronbach's alpha statistic.

Our main results provide evidence that both the direct and new indirect channels are in operation in the ICT-export link for Colombian manufacturing. In particular, the impacts of different ICT on export intensity are always positive, and there is also confirmation that previous experience in the using ICT for the firm's import activity affects the current firm's export performance. Further, we find that there is persistence in export performance and self-selection to continue exporting.

The rest of the paper consists of seven sections. In Section 2, we provide a review of the literature. Section 3 presents the data we use and some descriptive analysis. The empirical methodology and the empirical model are described in Section 4. Next, we present the empirical results in Section 5. Section 6 displays a discussion of the main results. Lastly, Section 7 concludes.

Literature Review

There is a prolific literature focused on analysing the impact of ICT both at the macro- and micro-level, especially in developed countries. In macroeconomics, the attention is centred on analysing the effect of ICT on countries productivity, and in microeconomics, on exploring the impact of these information technologies on different firms' issues such as productivity, innovation, and competitiveness, as well as on international trade. In what follows, we analyse the evolution of this literature, especially those studies related to the ICT-exports link, paying attention to the transmission channels.

The early macro studies show a total absence of defined channels of transmission because they focus on testing the *Solow's Paradox* (Solow, 1987), which states that information technologies (basically computer usage) have an insignificant impact on countries productivity (Brynjolfsson, 1993; Loveman, 1994; Oliner et al., 1994; Berndt and Morrison, 1995; Gordon, 1999; among others).

The evidence supports the existence of the paradox although some criticisms arise related to the production function assumptions (Biagi, et al., 2012) and the time elapsed for ICT to have positive effects (Turban, et al., 2007). Subsequent empirical research denies the existence of the paradox in the US economy and in several European countries (Jorgenson and Stiroh, 2000; Oliner & Sichel, 2000; Jalava and Pohjola 2002, Acemoglu, 2014; 2002; Van Ark et al., 2002; Pilat, 2004). This group of investigations suggests the first, but weak, transmission channels, since reduction in the price of computers, software, and communication equipment coincides with the increase of TFP. But if the countries' productivity boosted for additional reasons, it is plausible that the diffusion of information technologies was not the direct cause to improve trade practices or generate spillover effects.

The following set of studies for developed economies focus on analysing the link and causality effect between ICT and international trade at the country level (Caselli and Coleman, 2001; Onyeiwu, 2002; Ueki, et. al., 2005, Wallsten, 2005; Clarke and Wallsten, 2006; among others). These studies show two remarkable characteristics compared to previous macro research. First, they recognise that firms are the main vehicles where the transmission channels operate. Secondly, these channels could be analysed in two directions. Previous exporting firms are more prone to use ICT to communicate with clients and suppliers because it is cheaper compared to other methods, which in turn allows them to reduce transaction costs. But the reverse causality is also possible. If access to ICT makes it less expensive to find and communicate with potential customers in foreign markets, all else being equal, exports could be higher when the ICT use is progressive. This last channel and causality will be widely used in future research to demonstrate the existence of the ICT-export link in developed and developing countries. In this discussion, it is important to mention another element put forward by Yushkova (2014). According to this research, ICT effects could also impact importing activities, assuming that transmission channel is the same as in export activity; that is, the use of ICT might reduce transaction costs and trade barriers. However, we consider that there might be other specific elements associated to firms' imports when using ICT.

More recent studies move forward to analyse the effects of ICT at firm-level more thoroughly, accounting for firm heterogeneity using panel data, and by including other types of ICT different than Internet use (Ahmed and Ridzuan, 2013, Grazzi et al., 2016; Hagsten, 2015; Hagsten and Kotnik, 2017; among others). The transmission channel in these investigations is deeper and wider since they consider that the benefits of using and investing in ICT are related not only to the transaction costs reduction, but also the costs of entering foreign markets as well as coordination costs associated with production processes. In fact, when the analysis separately accounts for the firm decision to export and export performance, the existence of sunk costs constitute an additional precondition that affects the transmission mechanism. This is so as to establish distribution channels, explore foreign demand and competition, and customise products to suit foreign tastes, or comply with quality and safety legislation in other countries, and firms need to incur in some investments that not all firms can afford (Sanchis et al., 2022). Therefore, the benefits from ICT adoption are for a subset of firms that previously self-selected into the exporting markets (Roberts and

Tybout, 1997; Melitz, 2003). This possibly explains why, in emerging economies, it is difficult to establish a solid ICT-export linkage.

All previous research only considers direct channels of ICT towards exports, but in a more recent study, Añón Higón and Bonvin (2022) contribute to the discussion by pointing out that ICT could indirectly affect the intensity process through the potential enhancing effect of ICT on firms' productivity. This work introduces a new element in the transmission channel, since the role played by productivity has been analysed as a direct cause or consequence of ICT use (mainly in the macro literature), without considering that exports could also be affected by productivity gains obtained from these technologies. The introduction of this new channel implies the inclusion of firm past export experience and ICT in the law of motion productivity. The results they obtain support this new channel. In particular, they find that having a website has a direct effect on the likelihood to export and an indirect effect through enhanced productivity.

Studies in Latin America similar to the recent ones reported above are extremely scarce. The preliminary research is characterised by being mostly descriptive, carried out for SMEs in the largest economies by the Economic Commission for Latin America and the Caribbean, CEPAL (Botelho and Tigre, 2005; Ueki, 2005; Rodríguez Rodríguez, 2005). Transmission mechanisms in these works are not clearly defined, since the evidence suggesting that IT applications foster trade promotion is inferred from export figures (rather than from an empirical modelling using statistical methods), or by the number of signed international trade agreements and/or ICT adoptions. In the case of Colombia, we find no studies carried out on ICT. Nonetheless, Rodríguez-Crespo and Martínez-Zarzoso (2019) analyse the impact of Internet connection on international trade for 120 countries (including Colombia), but the transmission mechanism is also inferred from descriptive statistics.

The first research at firm-level in Latin America was proposed for Chile by Mathews and Bianchi (2010). We consider this is a quite relevant work as it proposes a conceptual model for the first time in this literature, and also because it considers that the indirect channels could be related, so the ICT-export link could be a more complex process than that analysed in previous studies. The Internet marketing capabilities (as online advertising or online sales) affect export growth directly and also affect it indirectly through the availability of export information (of competitors or clients) and business network relationships. Further, these indirect channels could also be connected as obtaining relevant information might enhance the learning processes that support exports and the development of firms' alliances. However, the empirical results are mixed because the evidence indicates that Internet marketing capabilities neither have a direct impact on export market growth nor have an indirect effect on business network relationships, what cast some doubts on the connection of the indirect channels. However, we think that this might be related to the fact that all ICT are strongly correlated and then the transmission channels are spread in so many ways that they could be redundant in some cases.

In relation to the above literature, our study considers that, in emerging economies, the ICT-export link could be explained by the well-known direct channel, but also by an indirect channel related on the complementarity between import and export activities. This channel has not been studied yet. The direct channel points

out firms' basic use of ICT to establish communication with clients or providers to share relevant information (prices, quality, discounts available, terms of payment, price of transport, and insurance) with the purpose of reducing uncertainty between traders, allowing more fluid transactions that in turn will increase firm's export activity (Racela & Thourmrunroje, 2020; Ozcan, 2018; Laudon et al., 2016). However, in emerging economies as Colombia, manufacturing imports are generally greater than exports (Lechuga Cardozo et al., 2017; Rosero, 2014), so we consider that the experience in the external purchase of capital goods (mainly machinery and transport equipment), construction materials, or embodied technologies requires a constant and properly use of ICT. The regular usage of these technologies might lead firms to improve learning processes and/or routines (Nelson and Winter, 1982), which in turn might facilitate future export activity due to the gained experience. This new channel implies including the effect of previous use ICT while being an importer only. In other words, we consider firms that have only imported in the past and count the number of years they use ICT and continue importing and then estimate the lagged impact of this variable on current exports.

Data and Descriptive Analysis

To explore the effect of ICT on export intensity, we merge three databases, namely, the Annual Manufacturing Survey (EAM), the Innovation and Technological Development Survey (EDIT), and the Annual ICT Manufacturing Survey (EAM-TIC). These datasets are published by the National Administrative Department of Statistics (DANE). We obtain firms' productivity, importing/exporting statuses, and other characteristics using the EAM survey. The investment in R&D activities and other innovation variables are drawn from the EDIT survey. Further, the information of ICT is obtained from the EAM-TIC survey. These databases collect information for all industrial establishments that operate in the country and are identified as industrial (according to the International Standard Industrial Classification, ISIC, Revision 4 adapted for Colombia). After merging the six waves (2013–2018) of the EAM and EAM-TIC surveys with three EDIT waves (EDIT VII, 2013–2014; EDIT VIII, 2015–2016; EDIT IX, 2017–2018), we obtain an unbalanced panel data with 41,093 SMEs observations corresponding to 8543 firms.

To analyse the influence of ICT on export performance for Colombian manufacturing, we start proxying for firms' ICT using five dichotomous variables and one continuous variable. Following Gomez, Mañez, and Sanchis (2022), we include the use of electronic devices, optical fibre, intra- and extranet, and different Internet uses. Further, we expand these variables if the firm has a website and the total firm's ICT expenditures per year.

The variable *electronic devices* include computers, laptops, tablets, cell phones, personal digital assistants, and mobile capture devices. *Optical fibre* allows firms to transmit information over longer distances and at higher bandwidths than electrical cables. The *intranet* is the private network that the Internet protocol technology uses to securely share information, operating systems, or computer services within an organisation. An *extranet* permits firms to share

Table 1 Firms' internationalisation strategies and ICT use

	<i>Electronic devices</i>	<i>Optical fibre</i>	<i>Extra and intranet</i>	<i>Internet uses</i>	<i>Website</i>	<i>ICT expenditures</i>
<i>All</i>						
<i>Only-export</i>	88.2%	59.6%	85.4%	45.5%	84.1%	2.91
<i>Only-import</i>	88.9%	59.4%	85.3%	43.4%	80.5%	2.96
<i>Both</i>	94.8%	71.4%	92.1%	60.2%	91.3%	2.91
<i>None</i>	74.2%	51.0%	77.9%	26.7%	62.0%	2.91
<i>SMEs</i>						
<i>Only-export</i>	86.9%	57.6%	84.3%	43.0%	82.5%	2.68
<i>Only-import</i>	87.8%	57.7%	84.5%	41.2%	78.9%	2.75
<i>Both</i>	93.0%	66.7%	89.9%	54.1%	89.2%	3.34
<i>None</i>	73.7%	50.5%	77.5%	26.0%	61.4%	1.91
<i>Large</i>						
<i>Only-export</i>	96.6%	73.4%	92.6%	62.9%	94.8%	4.45
<i>Only-import</i>	97.2%	72.7%	91.4%	61.3%	93.1%	4.58
<i>Both</i>	97.4%	77.9%	95.1%	68.8%	94.3%	4.94
<i>None</i>	91.3%	69.8%	91.9%	55.2%	82.8%	4.26

ICT expenditures are measured as the average expenditures on diverse ICTs (in logs)

internal information with suppliers, buyers, partners, clients, and organisations. The *different Internet uses* include sending or receiving e-mails, searching for information on goods/services, electronic banking, financial services, transactions with government agencies, customer service, online product distribution, personnel training, internal or external hiring, apps, or video conferences. Having *website* refers to a home page accessible through a specific domain and Internet address.

Table 1 reports the link between ICT and international trade. In general, regardless of ICT analysed, the figures reported in Table 1 reveal two remarkable patterns: the use of ICT for SMEs and the whole industry (*all*) is quite similar, and large firms (*large*) use ICT more intensively than SMEs.

Specifically, SMEs show that firms following the *only-export* and *only-import* strategy require a similar use of ICT for trading. However, the strategy of exporting and importing simultaneously (*both*) always shows a higher ICT use than the separate strategies. For instance, 93.0% of two-way traders use electronic devices, and 86.9% of *only-export* firms and 87.8% of *only-import* firms use this type of ICT. Further, firms that neither import nor export (*none*) always show the less intensive ICT use. Since SMEs are in the majority of companies in Colombia, the complete sample (*all*) in the upper panel follows a pattern similar to the pattern observe for SMEs.

The case of large firms is quite different (lower panel). Although the figures for firms exporting and importing at the same time are slightly larger than those for large firms that only import or only export (mostly in basic ICT, such as electronic

devices and websites), the use of these technologies displays a similar performance regardless of the internationalisation strategy. Furthermore, it is important to notice that firms without any international connection (*none*) display lower figures. Finally, large firms expend more than 13 times (double in logs) on ICT than SMEs.

These results indicate that it is appropriate to focus on SMEs rather than in the large firms or full samples. On the one hand, SMEs in Colombian manufacturing seem to be representative of the entire industry since they represent 92% of total firms. On the other hand, SMEs have a higher degree of heterogeneity in the ICT usage than large firms as this latter group does not face capacity problems and/or financial constraints, so the ICT adoption/diffusion among large firms is more homogenous.

Research Methodology and Empirical Modelling

To explore the effects of ICT use on firm's export performance (the *intensity process*), we use a dynamic generalised linear model (GLM) with panel data, provided that the dependent variable (foreign sales in total firm's sales) is a variable in proportion ranging between 0 and 1. Moreover, to deal with the possible bias from a non-randomly selected sample, we included the Heckman's lambda (Mills ratio) as a covariate. This implies that the firm's decision to export (*propensity process*) must be previously modelled and estimated (Gomez, Mañez & Sanchis, 2022).

We specify our model in terms of sunk costs (Roberts and Tybout, 1997) and a set of variables that proxy for the payoffs of export activity (Sanchis, Mañez, and Gómez-Sánchez, 2022). The model considers that firms continue exporting if the revenues exceed all costs, including sunk cost, related to export intensity. The existence of sunk cost requires the consideration of past export intensity as state variable in the firm's current exporting activity. These sunk costs are represented by the need to continue setting up marketing and distribution channels, exploring foreign demand and competition, customising own product characteristics to adapt them to foreign tastes, and/or meeting other countries' quality and security legislation (Sanchis, et al., 2022; Gómez-Sánchez, 2020).

As discussed above, we will introduce an indirect effect that would be captured through imports. In particular, we assume that the accumulated experience in the external purchase of capital goods (mainly machinery and transport equipment), embodied technologies, and other raw materials requires using some/all the ICT described. Using these technologies in regular basis would improve the learning processes and/or routines within the firm, which in turn might facilitate export performance

Specifically, we define a variable that captures the number of years a firm uses ICT while it is only importing (IEM_ICT_{it}). In this sense, to isolate the possible influence of export activities on the ICT use, we consider the firms that follow the strategy only-import in the period $(t-s)$ (with $0 < s \leq 6$ as the sample spans 6 years, 2013–2018). If in the subsequent period $(t-s+1)$ the firm starts to use ICT and continues only-importing, then (IEM_ICT_{it}) takes on the value 1, and if in the next period $(t-s+2)$ the firm continues using ICT and only-importing, then the experience variable takes on the value 2,

and so on. Subsequently, this variable is lagged one period and introduced in the empirical modelling in logs to capture its impact on current exports (t).

To measure firm's productivity, we use a two-equation system proposed by Wooldridge (2010), which can be jointly estimated by the generalised method of moments (GMM). The first equation solves the problem of endogeneity generated by the production factors that are chosen in the same period as they are consumed (freely variable factors; e.g. labour and materials), and the second equation is a Markov process that deals with the law of motion of productivity. Following De Loecker (2013), Kasahara and Rodrigue (2008), and Doraszelski and Jaumandreu (2013), we endogenise this process by including previous export status to account for possible *learning-by-exporting* (LBE) effects and also include past ICT usage to capture possible future improvement of firm's productivity. Once the TFP is estimated, we will include it in our model as a lagged variable to test whether the most productive firms self-select to export or to continue exporting markets (the self-selection/continuation hypothesis put forward by Melitz (2003)).

As previously mentioned, the ICT dichotomous proxies considered (electronic devices, optical fibre, intra-/extranet, Internet uses, and website) are strongly correlated because they are complementary inputs in the firm's productive process. Thus, we introduce them in the model one-by-one to avoid multicollinearity. We also include the ICT variables using two aggregate continuous ICT proxies: first, the firm's total ICT expenditures, and, second, an index that considers all ICT dichotomous proxies together, which is constructed using Cronbach's alpha statistic.² Both indicators try to capture the firm's ICT management in a single variable.

Considering all the above issues, the equation we estimate is as follows:³

$$EI_{it} = \beta_0 + \beta_1 EI_{it-1} + \beta_2 ICT_{it-1} + \beta_3 IEM_ICT_{it-1} + \beta_4 TFP_{it-1} + \beta_5 Z_{it-1} + \beta_6 \lambda_{it} + \beta_7 \overline{EI}_{pre} + s_j + v_t + \varepsilon_{it} \quad (1)$$

where EI_{it} is export intensity of firm i in period t . The variable EI_{it-1} will capture firm's sunk costs/persistence in export intensity. The set of ICT proxies is captured with the variable ICT_{it-1} . The variable IEM_ICT_{it-1} captures the indirect effect of importing on exporting for each of the ICT components, that is, the impact of previous ICT usage (in importing activities) on export performance. Besides, TFP_{it-1} allows testing of the self-selection/continuation hypothesis. Further, the vector Z_{it} includes a set of control variables that may affect firms' export intensity such as industry concentration, firm's mark-up, skilled labour, R&D activities, capital-labour ratio, and wages per worker. Furthermore, the Mills ratio (Hackman's lambda) to deal with the sample selection bias is represented by λ_{it} .⁴ Finally, s_j is a vector of industry dummies, and v_t is a vector of year dummies included to control for industry specific effects and macro conditions, respectively,

² Cronbach's alpha calculates the inter-item correlation/covariance into a single number that oscillate between 0 and 1. The general rule accepted is that alpha ranging from 0.6 to 0.7 indicates an acceptable level of reliability and 0.8 or greater a very good level. In this context, reliability must be interpreted as the use strength of the multiple correlated ICT.

³ The definition of the variables is shown in the Table 3 of the [Appendix](#).

⁴ The propensity process is estimated by a dynamic probit model. In this model, we estimate the Heckman's lambda. The dynamic probit model results are not reported but can be requested from the authors.

and ε_{it} is an error term. It is necessary to account for the possible existence of unobserved factors that may affect the firm's exporting intensity, such as exports department abilities, managerial skills, or product characteristics. With this aim, we assume that the error term has two components: $\varepsilon_{it} = a_i + \eta_{it}$, a firm-specific effect (a_i) and a transitory component (η_{it}). Therefore, we consider two possible sources of serial correlation in the error term. Regardless of whether η_{it} is independent across t , ε_{it} will always be serially correlated due to a_i .

In the estimation of the model for export intensity of Eq. (1), we control for correlated unobserved firms heterogeneity using the approach proposed by Blundell, Griffith, and Van Reenen (1999). This approach implies making assumptions about the distribution of the unobserved effect conditional on observed covariates and adopting a conditional maximum likelihood approach. Therefore, we model the distribution of a_i as:

$$a_i = b_0 + b_1 \overline{EI}_{pre} + \gamma_{it} \quad (2)$$

where $\overline{EI}_{pre}$ is the pre-sample mean of the export intensity. Blundell and Bond (1998) and Blundell et al. (2002) suggest that the firms' permanent effect might be captured by the entry pre-sample mean of the dependent variable, which should act as a sufficient statistic for unobserved firm heterogeneity. Finally, γ_{it} represents the error term which is assumed to be independent of the pre-sample mean of the dependent variable, the explanatory variables, and the idiosyncratic error term of the main equation. Since we use as the pre-sample period 2008–2012 and the explanatory variables in the export intensity equation, Eq. (1), are lagged one period, we perform the estimation procedure for the period 2013–2016.⁵

Results

Table 2 reports the estimated results for the performance of exporting SMEs. As discussed in previous sections, due to the strong correlation among the ICT variables, we include them one-by-one to avoid multicollinearity, so there are as many specifications as ICT considered. The set of ICT variables are proxied by 5 dummy variables (electronic devices, optical fibre, the use of extra-/intranet, Internet uses, and website) and also by two continuous variables (firm's ICT expenditures and the ICT index).

In general, the results show that all ICT proxies have a positive and statistically significant effect on the export performance, so there is evidence of ICT direct effects on firms export intensity for Colombian manufacturing. Specifically, in the set of dichotomous ICT proxies, the greatest impacts are shown by electronic devices (which increase the firm's export intensity by 16.2%) and having a website (10.1%). An intermediate effect is displayed by the use of intra-/extranet (8.9%), but lower influence is shown by optical fibre (6.7%) and different Internet uses (5.5%).

⁵ Experimenting with different pre-sample periods produced very similar results

Table 2 The impact of ICT on export intensity and SMEs

	Electronic devices	Optical fibre	ExtralIntra net	Internet uses	Website	ICT expenditures	ICT score
$El_{i,t-1}$	0.181*** (0.008)	0.179*** (0.008)	0.180*** (0.008)	0.179*** (0.008)	0.180*** (0.008)	0.181*** (0.008)	0.180*** (0.008)
$Devices_{i,t-1}$	0.162*** (0.037)						
$IEM_Devices_{i,t-1}$	0.009*** (0.003)						
$Optical\ fiber_{i,t-1}$		0.067*** (0.022)					
$IEM_Optical\ fiber_{i,t-1}$		0.006* (0.004)					
$ExtralIntranet_{i,t-1}$			0.089*** (0.033)				
$IEM_ExtralIntranet_{i,t-1}$			0.009*** (0.003)				
$Internet\ uses_{i,t-1}$				0.055** (0.022)			
$IEM_Internet\ uses_{i,t-1}$				0.005 (0.005)			
$Website_{i,t-1}$					0.101*** (0.036)		
$IEM_Website_{i,t-1}$					0.009*** (0.003)		
$ICT\ expenditure_{i,t-1}$						0.082*** (0.014)	
$IEM_ICT\ expenditure_{i,t-1}$						0.007** (0.003)	
$ICT\ score_{i,t-1}$							0.352*** (0.052)

Table 2 (continued)

	Electronic devices	Optical fibre	Extra/intra net	Internet uses	Website	ICT expenditures	ICT score
$IEM_ICT\ score_{t-1}$							0.007** (0.003)
TFP_{t-1}	0.267*** (0.063)	0.272*** (0.062)	0.263*** (0.062)	0.267*** (0.062)	0.268*** (0.062)	0.268*** (0.062)	0.268*** (0.063)
$Concentration_{t-1}$	0.010*** (0.003)	0.011*** (0.003)	0.011*** (0.003)	0.011*** (0.003)	0.011*** (0.003)	0.010*** (0.003)	0.011*** (0.003)
$Markup_{t-1}$	-0.132*** (0.045)	-0.143*** (0.045)	-0.136*** (0.045)	-0.140*** (0.045)	-0.140*** (0.045)	-0.131*** (0.045)	-0.141*** (0.045)
$Skill_{t-1}$	0.071*** (0.009)	0.073*** (0.009)	0.072*** (0.009)	0.070*** (0.009)	0.067*** (0.009)	0.053*** (0.008)	0.065*** (0.009)
$R \& D_{t-1}$	0.064*** (0.023)	0.070*** (0.023)	0.070*** (0.023)	0.066*** (0.023)	0.062*** (0.023)	0.056*** (0.023)	0.052*** (0.023)
KL_{t-1}	0.051*** (0.010)	0.051*** (0.010)	0.051*** (0.010)	0.052*** (0.010)	0.052*** (0.010)	0.049*** (0.010)	0.050*** (0.010)
$Wages_{t-1}$	0.033** (0.014)	0.039*** (0.013)	0.038*** (0.013)	0.038*** (0.013)	0.033*** (0.013)	0.007 (0.015)	0.022 (0.014)
$\overline{EI}_{pre}$	1.910*** (0.064)	1.917*** (0.063)	1.916*** (0.063)	1.917*** (0.063)	1.916*** (0.063)	1.920*** (0.063)	1.917*** (0.063)
$Constant$	-2.430*** (0.278)	-2.473*** (0.278)	-2.426*** (0.273)	-2.451*** (0.285)	-2.368*** (0.276)	-1.974*** (0.288)	-2.365*** (0.272)
Year/Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$Mills\ ratio$	0.305*** (0.034)	0.302*** (0.033)	0.301*** (0.033)	0.302*** (0.033)	0.305*** (0.033)	0.310*** (0.033)	0.310*** (0.033)
No. of Obs.	28,155	28,501	28,501	28,303	28,298	28,501	28,501

1. Robust standard errors are in parentheses

2. ***, **, and * mean statistically significant at the 1%, 5%, and 10% levels, respectively

In the case of the continuous ICT variables, we uncover that the firm's ICT expenditures contribute to increase exports by 8.2%, and the ICT index (*ICT score*) contributes to an increase of approximately 35%.

These results are partially in line with some findings carried out by Gomez-Sanchez et al. (2022) for the same country. Although this study focused on the export propensity process for all Colombian manufacturing firms (both SMEs and large firms), it also finds that the highest impacts come from using *electronic devices*, followed by the use of technologies that transmit information over longer distances (*optical fibre*) and sharing internal and external information with others (*extra-/intranet*). In this work, the authors conclude that the decision to export seems to be more affected by the use of those ICT that facilitate the firm's external communication than those related to internal communication. As both studies account for similar ICT proxies and cover the same period, we can conclude that ICT-export links operate differently as regards the decision to export or export intensity. In fact, our results suggest that the intensity export processes a less exigent process than the propensity process because export intensity can be enhanced by using basic ICT (such as electronic devices and website), but the firm's decision to export requires a more complex use of ICT.

Our results are in line with other results found for developing economies (Botelho and Tigre, 2005, Lal, 2004, Hinson and Sorensen, 2006) and for developed countries (Añón Higón and Bonvin, 2022, Hagsten and Kotnik, 2017; Hagsten, 2015). Similar to these works, there exists a remarkable ICT-export connection. However, it is worth mentioning that the set of ICT variables we use in this work are wider and include quantitative measures.

We also provide evidence of the indirect channel that operates throughout dynamic cross-effects from imports towards exports. Indeed, the parameter of IEM_{t-1} is positive and statically significant in the all ICT analysed, except for the variable *different Internet uses*. In this sense, we confirm that past experience in ICT usage associated to firms' import activity has a positive impact on firms' export performance. Specifically, the use of electronic devices, websites, and extra-/intranet in previous import activity increases current export firms' performance by 1%. Other ICT measures displaying a minor influence are optical fibre (0.6%), ICT expenditures (0.7%), and ICT index (0.7%). Although these impacts are not very large, possibly due to the short panel that we consider, we find evidence of its existence. It is important to note that the relationship between exports and imports is always analysed as the positive impacts in exports due to previous purchasing of raw materials that fosters the quality of final goods sold abroad (Sanchis et al., 2022). Nevertheless, this new evidence suggests that experience in ICT handling also contributes to this linkage between exports and imports.

We should highlight other relevant results obtained in our estimation exercise. Thus, the positive and significant parameter for the lag of export intensity (EI_{it-1}) in all specifications suggests that a firm's past export performance on international markets effectively affects current export performance. In this sense, we confirm that firms exporting face irrecoverable costs. So accounting for sunk costs is the right modelling strategy. Furthermore, the role of persistence in exporting

performance is reinforced by the positive and significant effect of the pre-sample means that control the permanent impact through the firm's individual effects.

In general, this outcome is similar to those obtained in Spain by Higón and Bonvin (2022) and to other studies more focused in the export propensity process (Hagsten, 2015 or Hangsten and Kotnik, 2017). Further, we also confirm that previously more productive firms self-select to continue exporting, since the coefficient of TFP is positive and statistically significant in all model specifications. These results are in line with multiple empirical research projects (Melitz, 2003; Máñez et al., 2020; Mathews and Bianchi, 2010; among others).

The control variables included in our model are also quite robust across specifications. The estimates suggest that SMEs with more skilled workers, paying higher wages, performing R&D activities, and operating in more concentrated industries show larger export performances in international markets. Further, the firm's mark-up displays a negative and significant impact on export intensity. This could be due to the fact that higher mark-ups worsen firms' competitiveness in international markets. This result is in line with the *pro-competitive effects hypothesis* (Edmon, et al., 2015); that is, if firms are exposed to more external competition, there could be gains due to reduced mark-ups. All these results are in line with those found for developed and developing countries (Gómez Sánchez, 2020; Máñez et al., 2020; Mañez & Love, 2019; Rehman, 2017, among others).

Furthermore, at the bottom of Table 2, the parameter of the inverse of Mills ratio is positive and statistically significant, regardless of the ICT variable analysed, which reveals that the firm's export decision (*propensity*) and the export performance (*intensity*) are related processes in Colombian manufacturing. Thus, the processes cannot be estimated separately, and the inclusion of the Heckman's lambda in the empirical modelling correctly deals with the non-random sample selection bias.

Lastly, we estimate Eq. (1) for the full industry and large firms (not shown in Table 2). The results for the full industry are quite similar to those obtained for SMEs. This is very much related to the high participation of these types of firms in the Colombian total industry (92%). Besides, in the case of large firms, the results are not conclusive, possibly because the diffusion of information technologies is more uniformly spread in those firms than in SMEs (or are used more intensively, as is shown in Table 1), so there is not variation among large firms. The few studies that separate by firm size to analyse the ICT-export link show similar results (Añón Higón and Bonvin, 2022).

Discussion of the Main Results

The results obtained in this study strongly suggest that ICT has a direct and positive impact on export performance (Hagsten, 2015; Hagsten and Kotnik, 2017, Añón Higón and Bonvin, 2022). We also uncover the existence of an indirect effect operating through the experience acquired in the use of ICT in firms' previous import activities.

Our findings also reveal that sunk costs are important to explain the *intensity* export process. In this sense, sunk costs not only determine whether firms decide to enter in international trade markets (*propensity process*), but also determines if the firms continue exporting (*intensity process*). In other words, as the international trade markets change

constantly, firms that are already exporting need to continue setting up marketing and distribution channels, exploring new foreign demands and competition, and customising their own products characteristics to adapt them to new foreign tastes and/or to meet other countries' quality and security legislation. Thus, sunk costs in this context must be understood as necessary costs to guarantee continuation in international markets (Máñez Castillejo et al., 2020). In the same vein, as the previously most productive firms can afford these sunk costs, we find evidence supporting the self-selection/persistence hypothesis into export markets. That is, firms need to maintain a minimal level of productivity to continue covering sunk costs to guarantee survival in export markets.

As regards the usage of ICT, our paper includes a broader spectrum of ICT items that enhance firm's communication capacity. In general, the previous literature is widely based on the use of Internet and webpages to study the ICT-exports link, which leads to some of them not being statistically significant because they are highly correlated. However, our results, obtained by introducing each ICT type each one by one, show that other different technologies, such as the extra- and intranet, optical fibre, or other measures of ICT (expenditures and the ICT index), are also important determinants of firms export performance in international markets.

In our approach, we have expanded the empirical evidence by introducing a new channel in the ICT-export link: the ICT experience while importing on exports intensity. Our results suggest that there exists an indirect transmission channel that is relevant to explain the ICT-export link for SMEs. Although recent empirical works include other indirect channels, the results are mixed, even for emerging economies (Bianchi and Mathews, 2016). The most recent study, carried out by Añón Higón and Bonvin (2022), also proposes a new indirect channel that operates through firm's productivity. We also account for this indirect channel as we consider an endogenous Markov process in the law of motion of productivity to estimate TFP (Wooldridge, 2010). In this sense, our work is more comprehensive as it includes the indirect channel that operates through productivity together with the indirect channel that operates through ICT experience with imports (previous to exporting). We consider this contributes to advance in the exploration of the ICT-export relationship.

The explanation related to the indirect channel is as follows. The experience gained by firms in the use of ICT on import activities also serves as a key element in exporting activity, because the continuous usage of ICT elements by manufacturing firms enhances their learning on how to manage those technologies more efficiently. In other words, the indirect channel is based on Nelson and Winter (1982) argument that states that firms could establish routines on import activities that strengthen the use of ICT due to the frequent contact with providers, banks, transporters, and customers. This experience allows knowing, learning, and specialising on trade international markets procedures, which remain recorded in the firm memory and are might be used in the future export activities. For instance, the previous use of *e-banking* on import activities generates skills and abilities in employees that are used to access, operate, and finalise international trade transactions, which are not very different from those related to exports, so the firms do not have to incur this learning process again when they sell abroad. In Colombia, this process has been reinforced by the creation of the Ministry of Information and Communication Technologies in 2009, since

it has recurrently promoted different types of strategic programs to promote not only access, but also the use and, above all, the appropriation of ICTs (especially in SMEs) in international trade (Gómez Sánchez, 2020).

Given the similarities that exist in the largest economies of Latin America, we infer that this channel could also be important for other emerging countries in the region (Argentina, Chile, Mexico, and even Brazil) given the similar volumes of imports of raw materials per year (Avendano, et al., 2020) and ICT use (Gómez Sánchez, 2020). In the same vein, as there exist strong linkages between imports and exports for firms in developed countries, such as Spain (Máñez Castillejo et al., 2020), we also claim that this transmission mechanism could play an important role in the empirical analysis of the ICT-export s link for these countries.

Conclusions

This study explores whether the usage of several ICT technologies has a direct and indirect impact on export intensity among Colombian manufacturing SMEs. To research this issue, we use an unbalanced panel data with 41,093 SMEs observations corresponding to 8543 firms. And we use a GLM dynamic panel data specification that also deals with the potential selection bias and multicollinearity problems associated to the different ICT technologies.

Our main findings indicate that (i) all the ICT technologies have a direct, positive, and significant impact on the export intensity of SMEs, but our evidence is inconclusive for large firms; (ii) many of the ICT technologies have an indirect, positive, and significant effect on export activities among SMEs, yet for large firms, the evidence is not decisive; (iii) firms communication capabilities are not limited to a few ICT, since other communication technologies beyond the Internet or web pages also show direct and indirect effects on the intensity of exports, as well as continuous and aggregate proxies such as ICT expenditures and the ICT index; (iv) there is also strong evidence of persistence in export intensity and self-selection to continue in export activities; (v) more concentrated industries, with positive expenditures in R&D activities, having skilled employees, and paying high wages, all contribute to improve export performance of SMEs in international markets; and (vi) firms' decision to enter export markets and firms performance on export markets are two related processes in Colombian manufacturing, so they cannot be analysed separately.

The ICT adoption by SMEs has been a quite recent and slow process in Colombian manufacturing. Among the factors that prevent its adoption are firms' productive capacity, financial constraints, labour skills, and mainly lack of knowledge of ICT adoption, mainly by SME entrepreneurs. Our results are encouraging since the SMEs performance in export markets (*intensity*) requires the adoption of fundamentally communication technologies that are considered standard, such as the Internet and website,

while the decision to export (*propensity*) requires a much more demanding combination of these technologies.

Our results point to the need that governments promote the access to and usage of ICT technologies in Colombian SMEs as a key vehicle for internationalisation. Firms that are just considering or planning to enter international markets should be supported in the adoption of information technologies that would allow them to know and make themselves known in international markets, such as the intranet/extranet that permits firms to access and share information of all types, as a way of reducing the uncertainty of buyers and sellers. Further, firms that are already operating in international markets require a different policy that should be more oriented towards the adoption of other ICT items (rather than the Internet and webpages), to boost export performance such as the use of *e-commerce*, *e-banking*, and *e-marketing* to enter different types of negotiations such as B2B (*business to business*), B2C (*business to consumer*), or C2B (*consumer to business*), among others.

Finally, it is important to mention that the empirical research on these topics agrees that transmission channels exist, and therefore, ICT reduce trade costs and barriers. Conceptually, the transmission channels have evolved from the simplest to the most complex; however, we consider that the measurement is still not clear as the empirical corroboration of their presence is done indirectly through model estimates. So, the real reduction of transaction costs related to the firm's internationalisation strategies when using ICT has not yet been properly quantified. Indeed, quantifying this impact would imply knowing all a firm's production costs, how many are related to exports/imports, and which of them are reduced due to the use of ICT. Up to now, no investigation has done so, probably due to the difficulty in knowing all the production costs of the firms in an industry for a country and, even more difficult, in emerging economies where the official statistics institutes have limited resources.

Appendix

Table 3 Description of the variables

Export intensity	Firm's foreign sales over total sales per year.
Devices	Dummy variable equal to 1 if the firm uses electronic devices: desktop computers, laptops, tablets, cell phones, electronic agendas or mobile capture devices; 0 otherwise.
Optical fibre	Dummy variable equal to 1 if the firm uses optical fibre; 0 otherwise.
Intranet and/or extranet	Dummy variable equal to 1 if the firm uses extranet and/or intranet; 0 otherwise.
Internet uses	Dummy variable equal to 1 if the firm uses the Internet to send or receive email, looks for information on goods and services, official agencies and authorities, electronic banking and other financial services, transactions with government agencies, customer service, online product distribution (delivery of products or services over the Internet), personnel training, and internal or external hiring. The use of applications telephone calls over the Internet/VoIP or the use of video conferences (Skype, etc.); 0 otherwise.
Website	Dummy variable equal to 1 if the firm has a website; 0 otherwise.
ICT expenditures	Logarithm of the firm's ICT expenditures per year.
ICT score	Cronbach's alpha statistic for the use of electronic devices, optical fibre, intra-/extranet, different Internet uses, and having website.
Total factor productivity (<i>TFP</i>)	Logarithm of total factor productivity.
Indirect effect of importing (<i>IEM</i> _ <i>ICT</i>)	Logarithm of number of years that a firm uses ICT while only importin after having started to import.
Market concentration (<i>concentration</i>)	Logarithm of Herfindahl-Hirschman index.
Mark-up (<i>markup</i>)	Logarithm of output elasticity of materials divided by the revenue share. The revenue share is the total cost of that input over the firm's total output.
Firm's size (<i>size</i>)	Logarithm of the number of employees in the firm.
Skill (<i>skill</i>)	Proportion of high-skilled labour in the firm's labour force.
R&D investment (<i>R&D</i>)	Dummy variable equal to 1 if the firm invests in R&D activities; 0 otherwise.
Capital-labour ratio (<i>KL</i>)	Logarithm of the capital over the number of employees in the firm.
Labor wages (<i>wages</i>)	Logarithm of wages per worker.
Pre-sample export intensity ($\overline{EI}_{pre}$)	Pre-sample means of the export intensity in 2008–2012.

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Declarations

Competing Interests The authors declare no competing interests.

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