



Does digitalization spur global value chain participation? Firm-level evidence from emerging markets

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ABSTRACT

Does digitalization by firms spur participation in Global Value Chains (GVCs)? Rapid strides in information and communication technology (ICT) through cost-effective and reliable telecommunications have facilitated multinational firms to outsource complex production activities across borders over the years. While the rise of GVCs to prominence has coincided with the ICT revolution, there is very little systematic empirical evidence at the firm-level documenting the nexus between digitalization of firms and their participation in GVCs. By using rich firm-level data for a sample of 24,839 firms across 52 countries spanning the period 2006–2018, we empirically test the importance of digitalization in deepening GVC participation. After correcting for potential biases arising from self-selection and reverse causality, our empirical analysis shows that digitalization by firms positively influences GVC deepening. Our results are quite robust to various measures of GVCs and digitalization. Further, we also document how digitalization boosts GVC integration of firms that are financially constrained.

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1. Motivation and contribution

Over the last three decades, rapid strides in information and communication technology (ICT) through more cost-effective and reliable telecommunications have coincided with multinational firms outsourcing complex production activities across borders (World Bank, 2020). Approximately 60 percent of global trade today comprises of trade in intermediate goods and services that are incorporated at multiple levels of the production networks for final consumption (Fig. 1).

The prevalence and continued expansion of global value chains (GVCs) across the world encompassing both cross-border trade and foreign direct investment (FDI) flows have come to occupy a significant place in understanding trends in global integration.¹ Sev-

eral studies have also reiterated the potential developmental benefits of GVCs, especially the ability of the resultant specialization through value chains to generate higher income and productivity gains, greater employment opportunities, and poverty reduction.²

While the rise of GVCs to prominence appears to have happened alongside the ICT revolution in general, there is very little systematic empirical evidence documenting the nexus between digitalization attempts by firms and their consequent participation in GVCs. There are some case studies that are largely qualitative in nature, which underline the importance of digitalization to firms' attempts to position themselves in global production networks. For instance, in a detailed case study of the Rwandan tea

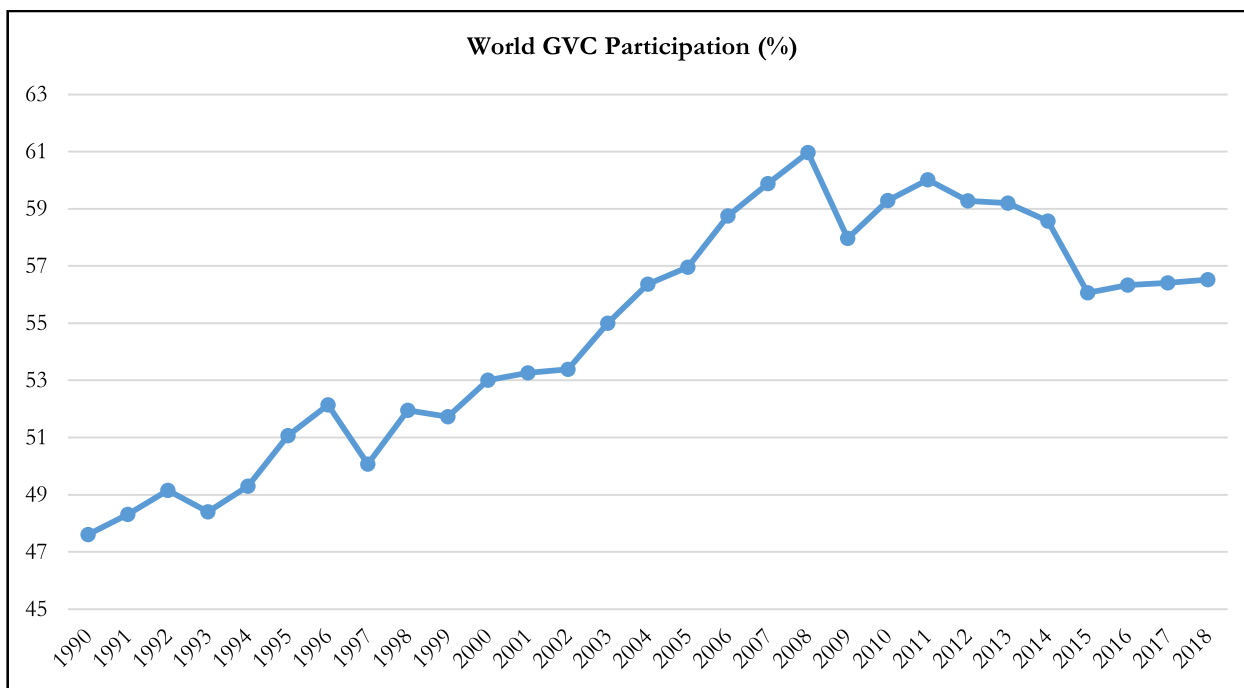
two stages being produced in different countries. A firm participates in a GVC if it produces at least one stage in a GVC" (p. 543). Furthermore, for a comprehensive overview on the importance and rise of GVCs in today's world, see among others, Gereffi (2014), Kano et al. (2020), Antras (2020) and Gopalan (2020).

² For instance, some estimates suggest that a one percent increase in participation in value chains can augment growth in per capita income by more than one percent, which is considered to be not only very economically significant but also bigger in magnitude than standard gains from international trade (World Bank, 2020).

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¹ In this paper, we follow the definition given by Antras (2020) "A global value chain or GVC consists of a series of stages involved in producing a product or service that is sold to consumers, with each stage adding value, and with at least



Source: UNCTAD EORA Database

Fig. 1. Global Trends in GVC Participation (1990–2018).

sector, Foster and Graham (2017) attempt to understand how tea firms plug themselves into GVCs. One of the interesting findings from their field research is the crucial role played by the digital infrastructure in the process of firms' integration into production networks, where in "digitally mediated exchange underlines the economic exchange and had significant effects on the way specific Rwandan firms were interacting" (p.79).³ While digital infrastructure can facilitate GVC participation, it also appears that such effects are asymmetric and biased towards the larger firms. In a related study, Foster et al. (2018) expanded their focus on a larger sample of firms in East Africa to investigate qualitatively the consequences of improved internet connectivity on firms that are part of GVCs. Interestingly, they point out that despite the fact that higher internet connectivity and greater adoption have benefitted firms in GVCs, these have accrued mostly to the larger firms, since smaller firms face higher barriers to GVC participation owing to a lack of wider set of digital capabilities.

Although such in-depth case studies provide valuable insights into the functioning of individual industries in specific countries, at a broader level, do the process of embracing digitalization deepen firms' participation in GVCs? A simple scatterplot depicting the relationship between digitalization and GVC participation at the country level (Fig. 2) suggests a strong positive correlation between countries with higher fixed broadband subscriptions and their GVC participation.

Beyond simple correlations at the aggregate country level, what can be said about the association between digitalization and GVC participation at the firm level? Can digital adoption enable financially constrained firms to integrate into GVCs? While seemingly obvious questions at first glance, to our knowledge, there has been

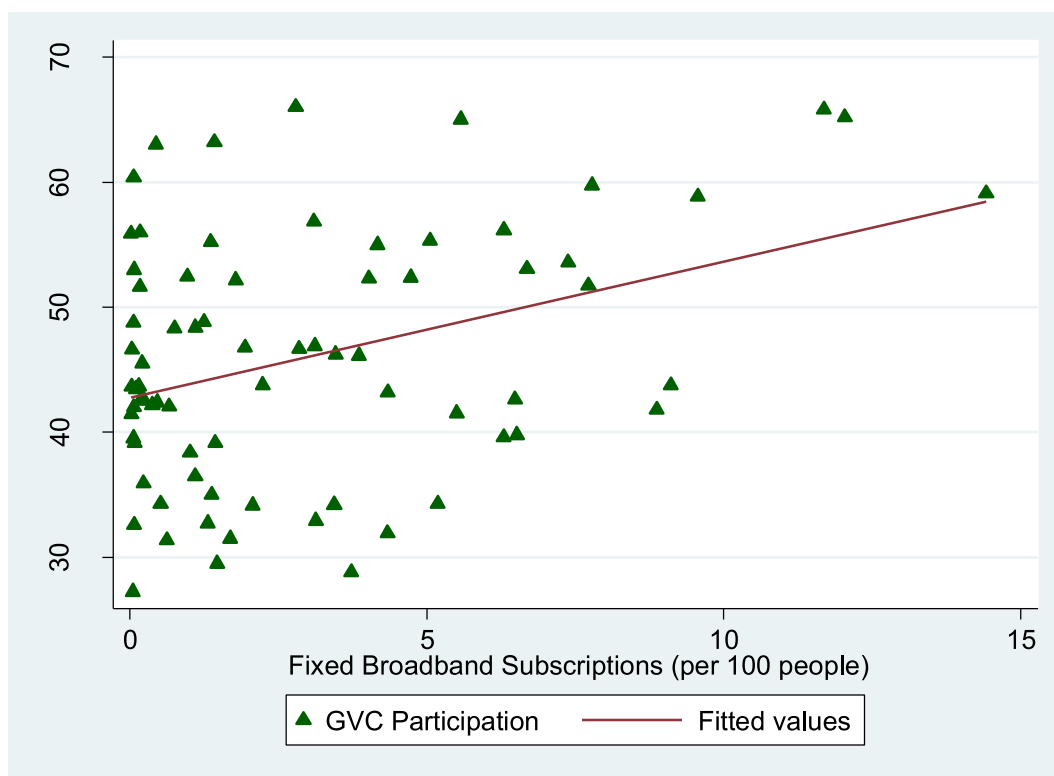
³ It is also worth bearing in mind that a nascent literature in the field of international business has explored the disruptive impacts of technological advancements like 3D printing on the configurations of GVCs across the world. See for instance the discussion in Laplume et al. (2016).

no academic work to date that attempts to understand these relationships at a firm-level and facilitate a cross-country comparison, something that we attempt to undertake in this paper.

We contribute to at least two related strands of studies that are of tangential interest to this paper. The first is a small but rapidly evolving empirical literature mostly at the aggregate country level that tries to understand the various factors that determine a country's participation in GVCs (see for instance, Cheng et al., 2015; Ignatenko et al., 2019; Fernandes et al. 2019 and references cited within, for a comprehensive overview of this literature). Most of these papers employ variants of panel regressions to identify several macroeconomic and institutional factors that explain a country's GVC participation, controlling for unobservable factors. A comparable smaller set of studies have also tried to address similar set of issues at the firm level for selected countries (See Wignaraja, 2013 for a firm-level analysis of selected East Asian countries and Lu et al., 2018 for a recent empirical analysis on China).

In this study, we aim to offer fresh and unique insights into understanding the role played by digitalization in facilitating GVC participation by undertaking a firm-level empirical assessment employing a wide variety of indicators. We extend this strand of literature in a novel way by exploring the GVC deepening of firms associated with digitalization. More specifically, our study goes beyond the usual dichotomy of classifying firms as GVC and non-GVC firms, and instead grouping them into four distinct categories: (a) deeply involved GVC firms, (b) firms that participate in GVCs, (c) exporting firms but are not involved in GVCs, and (d) domestic firms. By doing so, we offer an empirical assessment of the impact of digitalization on firms with different degrees of integration into GVCs.

The second strand of literature to which our study contributes pertains to the economic and social impacts of ICT in emerging and developing economies. While the empirical nexus between ICT and macroeconomic outcomes such as economic growth and productivity both at the country and firm-level has been explored quite ex-



Source: Authors' calculations based on UNCTAD EORA Database

Fig. 2. GVC participation and Fixed Broadband Subscription.

tensively (Donner and Escobari, 2010; Paunov and Rollo, 2015; and Niebel, 2018), more recent empirical work has attempted to understand how ICT adoption can affect corruption in many developing economies, with a greater focus on the Sub-Saharan African region (See Kanyam et al., 2017 and references cited within). Other studies have also attempted to empirically estimate the impacts of internet adoption on research and development (R&D) related knowledge flows within firms (Forman and Van Zeebroeck, 2019).

Within this strand, a set of studies have primarily analyzed the impact of digitalization on the export performance of firms. Fernandes et al. (2019) combine Chinese firm-level data with provincial information and show that access to internet had a positive impact on Chinese manufacturing exports. In a similar vein, Clarke (2008) uses firm-level data for small and medium enterprises (SMEs) from low- and middle-income countries in Eastern Europe and Central Asia and report that firms with internet access were more likely to export. Lederman and Pena (2020) also highlight that digital adoption in the form of email usage and website ownership results in a productivity premium of 1.6 percent and 2.2 percent respectively for a sample of 82 developing economies. At the country level, Freund and Weinhold (2002) report similar impact of internet penetration on services exports for a sample of 31 middle- and high-income countries, while Clarke and Wallsten (2006) show that the impact of internet access is not uniform since it boosts export performance in developing countries but not in developed economies.

While there is considerable academic interest in understanding the varied impacts of internet adoption or digitalization in general across emerging markets and developing economies (EMDEs), the association between digitalization and GVC participation has not been explored in systematic detail to date. Given this context,

we empirically address this question by combining both country and firm-level data on digitalization for a sample of 24,839 firms across 52 EMDEs, spanning the period 2006–2018 and test the significance of digitalization in spurring GVC participation.

Our paper attempts to tackle important empirical concerns about both self-selection bias and reverse causality issues. While we try and address self-selection bias by employing propensity score matching (PSM) techniques, we attempt to resolve reverse causality issues between digitalization and GVC participation by introducing different instrumental variables (IVs). Our first IV makes use of leave-one-out mean⁴ measures of digitalization to instrument the endogenous digitalization variable. By doing so, we draw information from industry homogeneity to draw inference on digitalization and GVC participation of the firms. Even though this approach does not fully solve the endogeneity issue,⁵ however, this type of instrument has been quite extensively used in the related literature (see for instance, Cette et al., 2021; Borowiecki et al., 2021).

As a potential alternative, we use the firms' training to its employees as an IV that can have an impact on its ICT adoption but plausibly exogenous to GVC participation. Our empirical strategy builds on Mushtaq et al. (2021) and Mbuysia & Leonard (2017), we

⁴ The "leave-one-out mean" measure refers to the instrument for the *i*th firm constructed as the industry average of digitalization while excluding the *i*th firm's level of digitalization. Previously Cette et al. (2021) & Borowiecki et al. (2021) have employed similar "leave-one-out mean" instruments in the ICT context. Section 3.1 of the paper has a more detailed explanation of how the instrument is constructed.

⁵ Despite its use in the related literature, a potential limitation of this IV could be that if a firm behaves similarly to other firms in the same industry, then industry-level adoption rates could be possibly endogenous, thus violating the strict exogeneity condition. We thank the editor for pointing this out.

posit that a firm providing formal training to its workers signals the possibility that the firm is already using ICT in its operations. Therefore, the need for training arises from firms' motive to further improve its ICT adoption. While providing training to its workers could indirectly improve the firm's chances of plugging into GVCs through skill upgrading, we do not see an explicit connection through which training will directly be correlated with higher GVC participation. Thus, the firm's decision to provide training to its workers is arguably correlated with its digitalization adoption (instrument relevance), but the only way it affects GVC participation directly is through its impact on digitalization (instrument exogeneity).

Finally, we also contribute to the literature by probing the relationship between how digitalization enables credit constrained firms to engage deeper in GVCs. A nascent firm-level literature on GVC participation has also identified that participation in GVCs involves substantial costs for firms. Particularly, financial constraints tend to be a significant impeding factor in a firm's decision-making process to participate in GVCs (See for instance [ADBI and ADB, 2016](#); [Lu et al., 2018](#); [Reddy and Sasidharan, 2020](#)). However, [Minetti et al. \(2019\)](#), based on a survey of Italian firms, highlight that financially constrained firms try to participate in GVCs in an attempt to establish ties with large international trading suppliers to broaden their source of liquidity. Using this as the prime motivation, we empirically test whether digitalization can play a role in aiding financially constrained firms to integrate into GVCs, while instrumenting credit constraints to address potential endogeneity issues.

To preview our main findings, after providing a battery of tests to tackle endogeneity concerns, we find that those firms that adopt digitalization are 6–10 percent more likely to participate in GVCs. Our analysis also underscores the importance of digitalization for financially constrained firms endeavoring to participate in global production networks. Finally, we extend our analysis to show that the advantages associated with internet adoption extend to SMEs, which is significant from a policy perspective. Finally, we document how digitalization fosters greater participation of firms from small agglomerates into GVCs and is not just confined to large agglomerates.

The remainder of the paper is structured as follows: [Section 2](#) lays out data and empirical strategy adopted in this paper. We offer a thorough discussion of the different metrics employed in our paper to measure GVCs, drawing on the firm-level literature. [Section 3](#) furnishes the empirical findings and also presents the results of our robustness exercises. [Section 4](#) concludes.

2. Data and empirical model

2.1. Data sources

To examine the relationship between digitalization and GVC participation, we rely on firm-level data from the World Bank Enterprise Surveys (WBES). The WBES database provides rich firm-level information drawn from a survey of random samples of firms across 144 economies. Considering that the WBES established a standardized questionnaire template since 2006, we restrict our analysis to cover the time-period of 2006 to 2018. It is also worth bearing in mind that since the WBES surveys are not carried out in regular intervals, it becomes difficult to construct a panel data at the firm-level, which therefore make a panel data estimation infeasible.⁶

⁶ As a robustness check, we use a two-year panel data set of firms belonging to 21 economies. However, due to the unavailability of panel data for the entire sample, we stick to pooled cross-sectional data for our main analysis. Thus, given that

As the next best alternative, we have constructed a sample of repeated cross-sections, which have also been adopted by other studies using the WBES database (See [Gopalan and Sasidharan, 2020](#) for a discussion). Further, we exclude firms with missing information on our focal variables capturing digitalization as well as countries and industries, which have less than five GVC and digitalization adopters. Finally, we also drop firms with missing information on sales. As a result, our final sample consists of 24,839 firm-year observations corresponding to total of 52 EMDEs.⁷ [Table A1](#) in the online supplementary annex showcases the levels of GVC participation and digitalization adoption by firms in our sample.

2.2. Empirical strategy

Our empirical strategy focuses on using a variety of firm-level measures representing both digitalization and GVC participation and check the importance of digitalization as a possible determinant of GVC participation. To that end, we estimate variants of the following parsimonious model of firm-level GVC participation:

$$GVC\ Participation_{ict} = \Phi(\alpha + \beta Digitalization_{ict} + Z + \gamma_t + \lambda_j + \zeta_c + \mu_{ict}) \quad (1)$$

We hypothesize a positive association between our measures of digitalization and GVC participation of a firm. As will be discussed below, considering that our firm-level GVC participation indicators are binary in nature, we estimate [Eq. \(1\)](#) using a probit model. In [Eq. \(1\)](#), the subscript i identifies a firm, c represents the country, j denotes industry, and t stands for time. In our firm-level model, Φ denotes the standard normal cumulative distribution.

We draw on data from the WBES and the existing literature to derive different indicators proxying GVC participation of a firm. The existing literature has resorted to multiple ways of defining what constitutes a GVC firm. For instance, according to [Harvie et al. \(2010\)](#), a firm participates in a GVC if it supplies to any tier of the supply chain and if the firm either imports intermediates or exports. [Wignaraja \(2013\)](#) identifies a GVC firm as a sustained exporter with at least 40 percent of its sales exported directly. While both these indicators place a relatively higher emphasis on firms' exporting aspects compared to their importing activities, the recent literature on GVCs define a GVC firm as one that is involved in international markets (either importing or exporting or two-way traders) with an internationally recognized quality certification ([Del Prete et al., 2017](#)).

It is pertinent to note here that despite the literature's extensive use of one of the above-mentioned measures, we find these to be very generic definitions that largely concern only the exporters. This appears to be inconsistent with the idea that a firm producing a good under the GVC framework involves participation of at least two countries thereby making them two-way traders i.e., firms that export and import simultaneously ([P. Antràs, 2020](#); [Urata and Baek, 2020](#); [Rigo, 2021](#); [Dovis and Zaki, 2020](#); [Ehab and Zaki, 2021](#); [World Bank, 2020](#)).

Hence, our first measure of GVC participation is a firm that exports and imports simultaneously (GVC-1). Our second metric to measure GVC participation follows a more restrictive definition, where we identify GVC firms (GVC-2) as those that not only simultaneously import and export but also have an internationally recognized quality certification ([Dovis and Zaki, 2020](#)). Unlike the earlier definitions of GVCs, which are more focused on export aspects, both our measures factor in the importing dimension of firms as

we are dealing with cross-sectional data, we refrain from interpreting our empirical results in the paper as causal relationships although they certainly reflect the associations between digitalization and GVC participation.

⁷ For a selected set of papers using the WBES database in the context of GVCs, see [Del Prete et al. \(2017\)](#), [Montalbano et al. \(2018\)](#).

well because importing is not only an essential component of GVC participation but also associated with backward integration into GVCs (Antras, P. 2020, Rigo 2021).

With regard to our focal explanatory variable of interest, i.e., digitalization of firms, we begin with a firm's most basic digital infrastructure – the internet. The simple use of internet in its operations enables firms to communicate with its customers, suppliers, distributors and workers regardless of their geographic position (Clarke, 2008; Hagsten and Kotnik 2017). Further, the use of internet also enables firms in acquiring faster and better information about various economic agents and market conditions, allowing it to internationalize (Mostafa et al., 2005). The use of internet also allows firms to reduce the dependence on costly middlemen, which are pivotal in establishing trade relations (Fernandes et al., 2019). Finally, as the related literature has pointed out, the use of internet also permits swift cross-border interactions among firms and provides a low-cost medium for participating in global markets (Kim, 2020).

Motivated by this strand of literature, we use two different measures of digitalization at the firm-level. First, we measure digitalization of a firm based on whether it has its own website. This variable captures the firms' use of information and communication services via a binary variable that takes the value 1 if a firm has its own website to communicate with a client or a supplier and to gain an online presence.

Second, as an alternative, we also capture firms' digitalization by examining if the establishment has high-speed internet connection (high-speed). An important constraint that we encounter is regarding the availability of information on this variable - only till 2014. Therefore, the period of study for which data on high-speed variable is available is confined to 2006–2014. Therefore, our sample drastically reduces to a total of 5077 firm year observations corresponding to firms belonging to 30 EMDEs compared to our first proxy (website), which has data for 52 EMDEs (24,839 firm year observations over 2006–2018).

We next offer a brief explanation of the vector of firm-level control variables captured in Z along with the expected priors.

- **Productivity:** The new-new trade theories posit firm productivity as the defining factor in a firm's decision to internationalize (Melitz, 2003). Hence, we account for the firm's productivity defined as the log of sales per worker. This measure is widely used in the literature as a measure of productivity (Fryges and Wagner 2008; Davies and Mazhikayev 2021).⁸ To check the robustness, we also measure productivity as value added per worker. We expect a positive impact of firm productivity on GVC participation on the firms.
- **Size:** We account for the scale effect by controlling for the size of the firm measured by the log of the number of employees. We expect larger firms to have considerable advantage in their endeavours to participate in GVCs.
- **Ownership:** It is well established that foreign-owned firms possess certain advantages than the domestic counterparts in terms of their access to resources and technology, and are more likely to participate in international trade (Rigo, 2017; Wignaraja, 2013). Firms affiliated to a business group enjoy better networking ties, and are more likely to export (Das et al., 2007). However, sole proprietorships are at a disadvantage given their lack of social ties and resource constraints. Conse-

⁸ Even though a more appropriate measure like total factor productivity (TFP) is preferred over labour productivity, we are unable to compute TFP since the data is cross-sectional in nature, and we do not have the necessary time series information for estimating the TFP. Further, the other data limitation refers to the lack of information on capital stock. A closer inspection of the data reveals missing information on capital stock for many enterprises, which significantly lowers the number of observations.

quently, we capture both foreign ownership (*Foreign*) and sole proprietorship (*Sole*) using a dummy variable. We expect positive association between foreign ownership and GVC participation, while we expect negative association of sole proprietorship on firms' decision to integrate into GVCs.

- **Age:** We also control for age of the firm. In terms of the age of the firm, existing studies report mixed results. Older firms having survived the competition have established networking ties enjoy scale effects, and face lower sunk costs increases their GVC participation (Urata and Baek, 2020; Minetti and Zhu, 2011). On the contrary, young firms are more adaptive to new production modes given their need to survive the competition (Upward et al., 2013), which may give them an edge.

In Table 1, we present the summary statistics of all the variables used in the empirics. From the table, we observe that number of GVC firms ranges from 28 percent of the sample for our GVC-1 metric to 15 percent for the more restrictive GVC-2 measure. Further, in terms of digitalization, while 58 percent of the sample firms have their own website, 88 percent of the firms report high-speed connection. In addition, a firm on an average employs 176 workers, and mean age is 29 years. We also notice that 11 percent of the sample firms are foreign owned, while almost 24 percent of them are sole proprietorship firms. In our empirical analysis, we also include country, industry, and year fixed effects, which account for changes in digitalization across countries, industries and changes over time.⁹

3. Empirical results

3.1. Baseline results and addressing endogeneity concerns

Table 2 shows the results of our baseline probit estimation. We report the marginal effects and columns 1–2 correspond to the use of website as the measure of digitalization, while columns 3–4 document the results for high-speed internet. We observe that the coefficients of both the digitalization variables are positive and statistically significant across the different measures of GVC participation. The marginal effects reported appear to suggest that firms having their own website are 6–8 percent more likely to participate in GVCs. This result is in line with the findings of Fort (2017), which reported that adoption of advanced communication technology (electronic data exchange, email, extranet) by US manufacturing firms during 2002–2007 was associated with a 3.1 percent increase in the probability of production fragmentation.

In terms of the impact of control variables in our model, we notice that larger and more productive firms¹⁰ are more likely to participate in GVCs. Similarly, foreign ownership also tends to promote GVC participation. We also find that sole proprietorship firms are at a disadvantage in their quest to participate in GVCs. Finally, our results also highlight that older firms are more likely to participate in GVCs.

Having established our benchmark results, we turn our attention to addressing the endogeneity issues present in our empirical setting to the best extent possible. It is a valid concern that our benchmark results could suffer from endogeneity, with the primary source of endogeneity bias stemming from the possibility of reverse causality where firms' integration into GVCs drive its digitalization adoption rather than the other way around. To address this concern, we rely on estimating a recursive bivariate probit model, which we further complement by estimating IV regressions using a

⁹ Table A1 in the supplementary online annex documents the level of GVC participation and digitalization adoption by firms across 52 emerging economies.

¹⁰ The results are robust while using value-added per worker as a metric of productivity. We thank an anonymous referee for this suggestion.

Table 1
Summary Statistics: Firm-Level.

Variable	Definition	Obs	Mean	Std.Dev.	Min	Max
GVC 1	WDR 2020 – Simultaneously exporting & importing	24,839	0.287	0.453	0	1
GVC 2	Simultaneously exporting & importing with a quality certification	24,839	0.154	0.361	0	1
Website	Equals 1 if a firm uses its own website; 0 otherwise	24,839	0.58	0.494	0	1
Highspeed	Equals 1 if a firm has high speed internet connection; 0 otherwise	5077	0.887	0.317	0	1
Size	Number of full-time workers	24,839	177.088	584.043	1	21,955
Ln Productivity	Log of sales per worker	24,839	13.462	2.843	0.095	27.573
Age	Number of years a firm has been in operation	24,839	29.741	17.701	3	166
Foreign	Equals 1 if 50% or more is owned by foreign firm; 0 otherwise	24,839	0.113	0.317	0	1
Sole	Equals 1 if sole proprietorship and 0 otherwise	24,839	0.237	0.425	0	1
CC	Ordinal variable; =4 if firm is a fully credit-constrained firm, 3 if the firm is partially credit constrained, 2 represents firms that maybe credit constrained and 1 representing firms that are not credit constrained	22,135	1.993	0.933	1	4
Finc	Equals 1 if firm is financially constrained and 0 otherwise	24,839	0.158	0.364	0	1
Email	Equals 1 if a firm uses an e-mail to communicate with a client or a supplier; 0 otherwise	24,839	0.857	0.35	0	1
GVC 3	Equals 1 if a firm engages in exporting and importing simultaneously and also uses technology licensed by a foreign owned company; 0 otherwise	24,839	0.087	0.281	0	1
GVC 4	Equals 1 if a firm is a two-way trading firm and has both a quality certification, and technology licensed by a foreign firm; 0 otherwise	24,839	0.057	0.233	0	1

Notes:
 1. Age and Size are measured in levels for the descriptive analysis.
 2. For the empirical analysis, log values of age and size are used.
 3. WDR- World Development Report.

Table 2
Baseline Regression: Probit Estimates.

VARIABLES	(1) GVC-1	(2) GVC-2	(3) GVC-1	(4) GVC-2
Website	0.0876*** (0.00555)	0.0767*** (0.00507)		
High Speed			0.0741*** (0.0222)	0.0883*** (0.0230)
Ln Size	0.0883*** (0.00182)	0.0632*** (0.00152)	0.114*** (0.00445)	0.0875*** (0.00378)
Ln Productivity	0.0220*** (0.00183)	0.0212*** (0.00154)	0.0465*** (0.00577)	0.0381*** (0.00496)
Ln Age	0.0176*** (0.00515)	0.0318*** (0.00410)	0.0319** (0.0132)	0.0451*** (0.0107)
Foreign	0.149*** (0.00750)	0.0791*** (0.00553)	0.184*** (0.0191)	0.120*** (0.0137)
Sole	-0.0488*** (0.00712)	-0.0335*** (0.00659)	-0.0594*** (0.0221)	0.00140 (0.0208)
Observations	24,839	24,839	5074	5074
Year Dummy	Yes	Yes	Yes	Yes
Industry Dummy	Yes	Yes	Yes	Yes
Country Dummy	Yes	Yes	Yes	Yes

Notes:
 1. All columns report the marginal effects.
 2. The proxy for digitalization is the use of Website and access to Highspeed internet connectivity.
 3. Standard errors are in parenthesis.
 4. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

set of plausibly exogenous instruments for the endogenous digitalization variable. As described earlier, both the outcome and the focal variables of interest in our empirical setup are binary in nature. Therefore, the use of an IV probit model produces inconsistent estimates (Bauernschuster et al., 2009; Wooldridge, 2010). Therefore, we estimate the following recursive bivariate probit models:

$$Pr(GVC\ Participation_{ict} = 1) = \Phi(\alpha + \beta Digitalization_{ict} + Z + \gamma_t + \lambda_j + \zeta_c + \mu_{ict}) \tag{2}$$

$$Pr(Digitalization_{ict} = 1) = \Phi(\Gamma + \delta Instrument_{ict} + Z + \gamma_t + \lambda_j + \zeta_c + \mu_{ict}) \tag{3}$$

In Eq. (2), GVC participation is expressed as a function of digitalization; firm and country specific controls as defined in vector Z

as given in Eq. (1). In Eq. (3), firm digitalization is expressed as a function of the same set of controls variables as in Z along with an appropriate instrument. Both Eqs. (2) and 3 are estimated simultaneously to control for endogeneity.

In terms of identifying a valid instrument, based on the extant ICT literature, we employ the industry average of website (highspeed) adoption excluding the firm’s own use of website (highspeed) as a possible instrument. By doing so, the individual firms’ digitalization adoption is explained by the variation in the sector-wide adoption of digitalization. The underlying rationale behind this sector wide leave-one-out mean instrument is that firms that use digitalization more actively to increase their GVC presence than the sector average, the firm will be more exposed to sector-wide technology advances which lower their adoption cost (Borowiecki et al., 2021). Hence, it is through this spillover effect that the instrument achieves identification. Further, incorporation of sector fixed effects accounts for unobserved sector specificities, and as a result, the only way our instrument affects GVC participation of the firm is through the individual ICT adoption of firms (Cette et al., 2021).¹¹

Table 3 also shows the results of our recursive bivariate-probit estimation. From the table, we observe a positive association between firm digitalization and GVC participation. Based on the marginal effects reported, we can note that website adoption increases the probability of a firm integrating into GVCs in the range of 10–14 percent. Similarly, a one standard deviation increase in firm’s access to high-speed internet connectivity makes a firm 6.5–7.8 percent¹² more likely to participate in GVCs vis-à-vis those that do not have such an infrastructure setup at their disposal.

It is pertinent to note that the economic significance of our digitalization proxies tends to be higher once accounted for endogeneity, as reflected in the larger coefficients relative to the baseline estimates. This possibly highlights that a failure to account for

¹¹ Previously, Cette et al. (2021) & Borowiecki et al. (2021) have employed sector-wide leave-one-out mean instrument to endogenous ICT adoption of French and Dutch firms. In a cross-section set-up, other studies have also employed similar instruments to tackle such endogeneity concerns (For instance, see, Alby et al. (2013); Amin & Islam (2021); Amin & Soh (2021); Clarke et al. (2015); DAVIS & Zaki (2020); Ehab & Zaki (2021)).

¹² The magnitude is calculated as $[\exp(\text{coefficient} \times \text{standard deviation}) - 1] \times 100$.

Table 3
Bivariate Probit Estimation with Instruments: Leave-One-Out Mean of Digitalization.

	(1) GVC-1	(2) GVC-2	(3) GVC-1	(4) GVC-2
Website	0.147*** (0.0113)	0.101*** (0.0137)		
High Speed			0.200*** (0.0587)	0.238*** (0.0563)
Ln Size	0.0743*** (0.00171)	0.0546*** (0.00162)	0.117*** (0.00417)	0.0894*** (0.00357)
Ln Productivity	0.0145*** (0.00115)	0.0154*** (0.00112)	0.0170*** (0.00260)	0.0124*** (0.00220)
Ln Age	0.0184*** (0.00330)	0.0256*** (0.00295)	0.0325*** (0.0119)	0.0443*** (0.0101)
Foreign	0.0796*** (0.00495)	0.0503*** (0.00403)	0.192*** (0.0170)	0.128*** (0.0124)
Sole	-0.0462*** (0.00462)	-0.0320*** (0.00482)	-0.0659*** (0.0209)	-0.00834 (0.0201)
First Stage				
Website_Mean	0.157*** (0.00450)	0.0791*** (0.00529)	0.101*** (0.0136)	0.0659*** (0.0133)
Highspeed_Mean				
Year Dummy	Yes	Yes	Yes	Yes
Industry Dummy	Yes	Yes	Yes	Yes
Country Dummy	Yes	Yes	Yes	Yes
Observations	24,352	24,352	4916	4916

Notes:.

1. All columns report the marginal effects.
2. The proxy for digitalization is the use of Website and access to Highspeed internet connectivity.
3. Standard errors are in parenthesis.
4. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

endogeneity tends to induce a downward bias in the estimated coefficients.¹³ Further, in terms of the instrument used, our instrument appears to satisfy the relevance condition as shown by the positive and significant coefficient of the instrument in the first stage IV regressions. Finally, in terms of the controls, we find more productive, large, older and foreign owned firms are more likely to participate in GVCs. This finding is similar to our benchmark result and in line with the existing literature (Lu et al., 2018; Rigo, 2017; Urata and Baek, 2020; World Bank, 2020).

As a plausible alternative, we introduce firms' training to its employees as an instrument that can have an impact on its ICT adoption but exogenous to GVC participation.¹⁴ The use of training as an IV is based on Mushtaq et al. (2021) and Mbuysia & Leonard (2017). The rationale behind using training as an instrument is based on the assumption that a firm providing formal training to its workers signals the possibility that the firm is already using ICT in its operations. Hence, the need for training stems from the firm's motive to further improve upon its ICT adoption. Additionally, by providing training to its workers, a firm improves its quality of workforce, which in turn might make them capable of joining the GVCs through obtaining quality certification and forming network ties with lead firms. However, the existing literature does not document a direct channel through which training impacts GVC participation of the firms. Therefore, the instrument satisfies the exogeneity condition. The training variable is a binary variable which takes the value 1 if a firm provides formal training programs for its workers and 0 otherwise. Table 4 reports the results of this exercise and as the results show; we find that our benchmark results continue to be robust when we instrument digitalization with firms' training to its workers.

¹³ We thank an anonymous reviewer for raising this point.

¹⁴ As a third alternative instrument, we have used a measure of informal competition as an instrument for ICT, which allows us to factor in industry heterogeneity. This instrument has also been recently applied in Haini (2021) in a similar context. We find that our benchmark results using this IV are robust for website, highspeed and email variable.

Table 4
Alternative Instrumental Variable – Training to Employees.

	(1) GVC-1	(2) GVC-2	(3) GVC-1	(4) GVC-2
Website	0.195*** (0.00855)	0.197*** (0.00821)		
High Speed			0.319*** (0.0463)	0.367*** (0.0365)
Ln Size	0.0669*** (0.00140)	0.0471*** (0.00105)	0.109*** (0.00411)	0.0832*** (0.00356)
Ln Productivity	0.0123*** (0.00102)	0.0129*** (0.000951)	0.0168*** (0.00246)	0.0117*** (0.00215)
Ln Age	0.0180*** (0.00301)	0.0235*** (0.00260)	0.0321*** (0.0115)	0.0454*** (0.00945)
Foreign	0.0680*** (0.00450)	0.0421*** (0.00354)	0.185*** (0.0172)	0.125*** (0.0127)
Sole	-0.0461*** (0.00414)	-0.0270*** (0.00408)	-0.0615*** (0.0195)	-0.000865 (0.0190)
First Stage				
Training	0.0427*** (0.00192)	0.0331*** (0.00168)	0.0362*** (0.00500)	0.0311*** (0.00430)
Year Dummy	Yes	Yes	Yes	Yes
Industry Dummy	Yes	Yes	Yes	Yes
Country Dummy	Yes	Yes	Yes	Yes
Observations	24,753	24,753	5068	5068

Notes:.

1. All columns report the marginal effects.
2. The proxy for digitalization is the use of Website and access to Highspeed internet connectivity.
3. Training to employees is used as an instrument for digitalization (both website and highspeed).
4. Standard errors are in parenthesis.
5. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Beyond reverse causality, we also attempt to deal with possible self-selection concerns among firms, an issue well-documented in the firm-level trade literature, where productive firms may find it easier to integrate into international markets (Melitz, 2003). To address this issue, we employ a propensity score matching (PSM) estimator proposed by Rosenbaum and Rubin (1983).¹⁵ Table A2 in the supplementary annex summarizes the results of our balancing tests, which reveal that after matching we observe no difference between the treatment and control group in terms of firm features, with the only difference between the groups being their decision to participate in GVCs. Following the successful matching of GVC and non-GVC firms, we re-estimate Eq. (1) on the matched sample. Table A3 documents the results of this analysis, which shows that the impact of digitalization is positive and significant across all specifications highlighting that digitalization acts as a key driver in firms' decision to integrate in GVCs.¹⁶

Finally, as mentioned earlier, we also go beyond the usual dichotomy of classifying firms as GVC and non-GVC firms and instead classify our sample firms into four categories: (a) purely domestic firms; (b) exporting firms but those that are not involved in GVCs; (c) firms which participate in GVCs, and (d) firms that are deeply involved in GVCs. We distinguish between these four different groups of firms with respect to their involvement in GVCs

¹⁵ The PSM technique allows us to create a group of control firms, which in the present setting involve a group of non-GVC firms which are similar in characteristics to the GVC firms. The only difference between the two groups after a successful match is that of the treatment effect in participation in GVCs. The PSM matches firms based on observables and as a result, we match firms based on their productivity, size, age, and foreign ownership of the firm. The matching of the treatment group (GVC firms), and the counterfactual group (non-GVC firms) is based on the propensity score, which we estimate using a probit model and the kernel matching estimator. The key characteristic of the kernel matching estimator is that it uses all the observations for estimating the propensity score.

¹⁶ The results are further robust to using an alternative matching estimator (nearest neighbour matching). The results are available upon request from the authors.

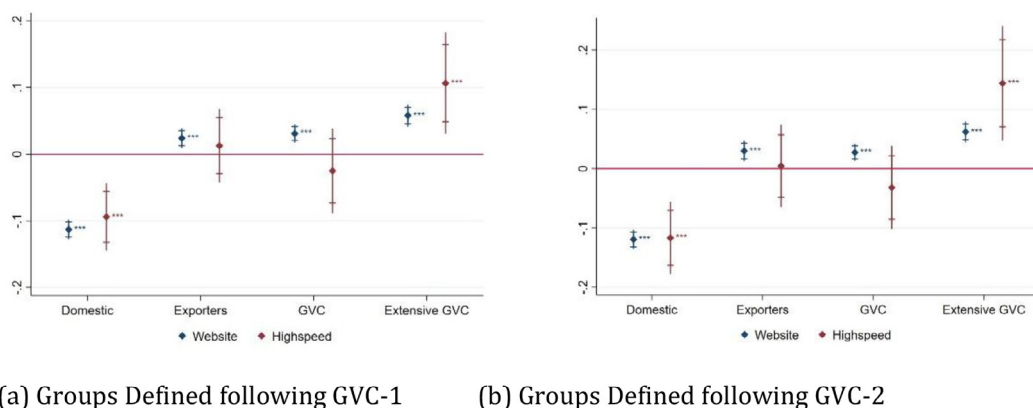


Fig. 3. Multinomial Logit Estimates - Impact of Digitalization on Degrees of GVC Integration.
 Notes: In panel (a) GVC firms are firms that export and import simultaneously with less than 10% of export sales. Subsequently, extensive GVC firms in panel (a) are those GVC firms which exports at least 10% of its sales. Similarly, in panel (b) GVC firms are firms that import and export simultaneously and also have an internationally recognized quality certification. Further, these firms have export sales less than 10%. All other GVC firms with export sales greater than 10% are extensive GVC firms in panel (b).
 Source: Authors.

which allows us to assess the impact of digitalization on firms with different degrees of integration into GVCs.¹⁷

We define Group 1 as pure domestic firms, i.e., firms that do not engage in any trade activities. Group 2 represents the set of pure exporters, which are firms that export but are not integrated into GVCs, identified by their lack of involvement in importing activities. Group 3 and Group 4 firms are both GVC firms. However, we distinguish firms in the two groups based on their level of engagement in GVC activities, i.e., differentiating between extensive GVC firms from those that operate at the periphery of GVC. Consequently, Group 3 represents the GVC firms, which have exports less than 10% and Group 4 are deeply integrated firms with exports greater than 10% of their sales. Based on these defining characteristics, we have an ordinal variable, which takes the value 0 for domestic firms, 1 for exporting firms, 2 for peripheral GVC firms (Group-3), and 3 for deeply integrated GVC firms (Group-4).

Subsequently, we estimate a multinomial logit model and find that digitalization encourages a deeper level of globalization, consistent with our benchmark results. We plot the marginal effects from this multinomial logit regression in Fig. 3. As we can observe, firms that adopt digitalization promote their participation in trade activities relative to those with just domestic market operations. A closer inspection of marginal effects also reveals that digitalization benefits firms deeply integrated in GVCs (extensive GVC in Fig. 3, panels (a) & (b)). Further, the adoption of website and highspeed connectivity has a relatively greater impact on Group-4 firms. Hence, our results reiterate our baseline finding that digitalization acts as a channel through which firms can increase their presence in GVCs.

3.2. Digitalization and credit constraints

The nascent firm-level literature on GVC participation has identified that participation in GVCs involves substantial costs for firms. Particularly, financial constraints tend to be a significant impeding factor in a firm's decision-making process to participate in GVCs (See for instance ADBI and ADB, 2016; Lu et al., 2018; Reddy and Sasidharan, 2020). This is largely due to the presence of substantial fixed investment that a firm has to undertake in order to participate in global markets, which becomes extremely strenuous for

financially constrained firms. However, Minetti et al. (2019), based on a survey of Italian firms, highlight that financially constrained firms engage in GVCs in an attempt to establish ties with large international trading suppliers to broaden their source of liquidity. Given this context, to what extent can digitalization boost the chances of financially constrained firms to engage deeper in GVCs? We explore this connection further by empirically testing the significance of and magnitude to which digitalization can play a role in aiding financially constrained firms to integrate into GVCs.

To tease out these connections, we first construct a comprehensive measure of the firm's credit constraints originally based on Kuntchev et al. (2012). Our credit constraint (CC) variable is an ordinal variable ranging from 1 to 4, with 4 representing a fully credit-constrained firm, 3 capturing firms that are partially credit constrained, 2 representing firms that maybe credit constrained and 1 representing firms that are not credit constrained (Gopalan and Sasidharan, 2020).¹⁸ To understand if digitalization of firms enhances participation of financially constrained firms into GVCs, we interact the two variables of interest – digitalization and credit constraints.

Table 5 shows the results for a representative set of GVC indicators. Three points are worth noting from the results. First, as expected and consistent with the literature, higher credit constraints tend to deter GVC participation. Digitalization on the other hand on its own tends to spur GVC participation, consistent with the results established so far. With regard to the joint association between the two variables, we find that the coefficient of the interaction term (Website*CC or highspeed*CC) is positive across all specifications suggesting that as the extent of financial constraints faced by the firms increase, embracing digitalization in their operations allows firms to enhance their participation in GVCs. These results are suggestive that firms with higher credit constraints benefit from the adoption of digital infrastructure due to greater efficiency in communication and operations, also spurring their participation in GVCs. These findings also highlight an avenue for financially constrained firms to participate in GVCs.

¹⁸ Fully credit-constrained firms are the firms who had their loan applications rejected or did not even apply for a loan despite a need of capital infusion. As a result, a fully credit-constrained firm does not have any external loans with them. Partially credit-constrained and maybe credit-constrained are two intermediate categories. Finally, not credit-constrained firms are firms which are content with their current financing set-up (Gopalan and Sasidharan, 2020).

¹⁷ We are grateful to an anonymous reviewer for suggesting this to us.

Table 5
Bivariate Probit Estimation: Digitalization and GVCs in Credit Constrained Firms.

	(1) GVC-1	(2) GVC-2	(3) GVC-1	(4) GVC-2
Website	0.151*** (0.0396)	0.330*** (0.0246)		
Highspeed			-0.133 (0.141)	0.0535 (0.134)
CC	-0.0228*** (0.00357)	-0.0321*** (0.00352)	-0.0117 (0.0121)	-0.0242* (0.0124)
Website*CC	0.0385*** (0.00275)	0.0350*** (0.00279)		
Highspeed*CC			0.0292*** (0.0105)	0.0317*** (0.0112)
Ln Size	0.0764*** (0.00479)	0.0345*** (0.00290)	0.131*** (0.00728)	0.0988*** (0.00599)
Ln Productivity	0.0174*** (0.00253)	0.00421*** (0.00134)	0.0159*** (0.00317)	0.0121*** (0.00266)
Ln Age	0.0136** (0.00563)	0.0281*** (0.00452)	0.0314** (0.0141)	0.0458*** (0.0115)
Foreign	0.152*** (0.00821)	0.0852*** (0.00611)	0.197*** (0.0202)	0.126*** (0.0146)
Sole	-0.0397*** (0.00837)	-0.0217*** (0.00799)	-0.112*** (0.0288)	-0.0410 (0.0306)
First Stage				
Website_Mean	0.588*** (0.062)	0.588*** (0.062)		
Highspeed_Mean			0.472*** (0.176)	0.472*** (0.176)
Year Dummy	Yes	Yes	Yes	Yes
Industry Dummy	Yes	Yes	Yes	Yes
Country Dummy	Yes	Yes	Yes	Yes
Observations	21,704	21,704	4336	4336

Notes:

- All columns report the marginal effects.
- The proxy for digitalization is the use of Website and access to Highspeed internet connectivity.
- Standard errors are in parenthesis.
- *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

One of the possible empirical concerns that we have to address here is that credit constraints could likely be endogenous when assessing the relationship between firms' digitalization and GVC participation.¹⁹ Other studies in the tangential strands of literature have also pointed out to the possibility of joint determination of GVC participation and financial constraints (see for instance Minetti et al., 2019). To explicitly account for this, we attempt to instrument our measure of credit constraints. However, we must note that in the presence of a binary endogenous variable, instrumenting an ordinal variable (cc) in the bivariate setup is econometrically infeasible. Hence, to overcome this concern, we use a different binary indicator of a firms' financial health. The new dummy variable (*finc*) identifies financially constrained firms as firms that do not have a line of credit either because they applied for a loan and did not obtain it, or they did not apply for a loan due to one of the following reasons: (i) complex application procedure; (ii) unfavorable interest rates; (iii) high collateral requirements; (iv) insufficient size and maturity period of loan; (v) did not believe that the application will be approved.

Given the binary nature of the dependent variable and two binary endogenous variables (digitalization and credit constraints), we employ instead a multivariate probit analysis to estimate the said relationships of interest. We introduce two possible variables to instrument financial constraints. First, we use the level of *hard* information available for the firm tapping into data on whether the

firms audit their balance sheets or not. To that end, the instrument *audit* takes the value 1 if the balance sheet of the firm is certified by an external auditor; and 0 otherwise. The second instrument (*cf*) draws on the limited availability of internal funds available within the firm. In this regard, firms surveyed in the WBES are asked the proportion of "Material inputs or services paid for after delivery" in the last financial year. Using this information,²⁰ we create a dummy variable which equals 1 for firms in the top 2 tercile of the distribution and 0 otherwise. Following Pietrovito and Pozzolo (2021), we can argue that firms that allow for payment post-delivery are less financially constrained. However, on the other hand, a prolonged delay in the payment on behalf of the customer may be suggestive of weak financial health of a firm (Nucci et al., 2020). Although we believe that the instrument has significant power to account for the endogeneity of financial constraints, the literature remains agnostic concerning the direction of the instrument (Nucci et al., 2020).

Table 6 shows the results of this analysis using the two instruments discussed above. As we can observe, digitalization continues to be positive and statistically significant, consistent with our baseline estimates. Further, the coefficient of our binary financial constraint variable (*finc*) is negative and significant, highlighting that financial constraints impede the GVC participation of firms. Finally, the coefficient of interest here – the interaction between the digitalization measure and financial constraint – is positive and significant in the case of Website adoption. The result highlights that website adoption helps financially constrained firms increase their GVC presence.²¹ The results also document the robustness of our findings to alternative measures of financial constraints.

3.3. Robustness checks and extensions

We undertake further robustness checks to verify the consistency of our benchmark findings regarding strong and robust positive association between firm digitalization and its GVC participation. First, we employ two alternative definitions of GVCs and re-examine the sensitivity of our results. Second, we use an additional measure of digitalization to check if our baseline results still continue to remain robust.

Regarding the alternative definitions of GVC participation, we adopt a more restrictive definition of GVCs by defining a firm's GVC participation (GVC-3) as a binary variable which takes the value 1 if a firm engages in exporting and importing simultaneously and also uses technology owned by a foreign owned company (0 otherwise). This definition takes into account the flow of knowledge and technical know-how between a lead MNC and a domestic supplier (P. Antràs, 2020; World Bank, 2020), highlighting the closely-knit relationship between agents involved in a GVC framework.

Second, we impose an additional restriction on GVC-3 to derive our second alternative measure of GVC, i.e., GVC-4. Drawing on GVC-2 & GVC-3, our GVC-4 measure is the most stringent of the lot taking a value of 1 if a two-way trading firm has both a quality certification and technology licensed by a foreign firm. This variable would in turn capture the firms which are truly embedded in the GVC framework. The stringent nature of the definition is illustrated in Table A1, which highlights that the number of GVC-4 firms is the lowest across all countries in comparison to firms captured by GVC-1, GVC-2 and GVC-3. Within the overall sample,

²⁰ The data from the survey is continuous in nature. However, given the skewed distribution of the variable, we use a binary variable following a strategy previously employed in the literature (See Pietrovito & Pozzolo, 2021).

²¹ While the interaction term between website and financial constraint turns out to be insignificant for GVC-2, the estimation fails to achieve convergence with respect to the highspeed variable and GVC-2. In order to maintain uniformity, we present the results for website and highspeed for GVC-1.

¹⁹ We thank an anonymous reviewer for raising this possibility.

Table 6
Multivariate Probit: Instrumenting Credit Constraints.

VARIABLES	GVC-1	GVC-1
Website	0.462*** (0.0468)	
Highspeed		0.206 (0.154)
Finc	-0.268*** (0.0727)	-0.680* (0.372)
Website*Finc	0.155** (0.0672)	
Highspeed*Finc		0.705** (0.348)
Ln Size	0.365*** (0.0101)	0.420*** (0.0197)
Ln Productivity	0.0938*** (0.00762)	0.163*** (0.0192)
Ln Age	0.0699*** (0.0224)	0.105** (0.0489)
Foreign	0.630*** (0.0323)	0.687*** (0.0695)
Sole	-0.192*** (0.0322)	-0.199** (0.0843)
First Stage		
Website_mean	1.747*** (0.0396)	
highspeed_mean		1.825*** (0.123)
Audit	0.0215 (0.0212)	0.132** (0.0570)
Cf	0.159*** (0.0207)	-0.0548 (0.0577)
Year Dummy	Yes	Yes
Industry Dummy	Yes	Yes
Country Dummy	Yes	Yes
Observations	24,352	4916

Notes:
 1. All columns report the marginal effects.
 2. The proxy for digitalization is the use of Website and access to Highspeed internet connectivity.
 3. Financial constraints are instrumented using firms' information on: (i) whether a firm is audited, and (ii) the availability of internal finance with the firm proxied through delayed payments.
 4. Standard errors are in parenthesis.
 5. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
 6. While the interaction term between website and financial constraint turns out to be insignificant for GVC-2, the estimation fails to achieve convergence with respect to the highspeed variable and GVC-2. Hence, to main uniformity, we only present the results for website and highspeed for GVC-1.

while 8 percent of the firms are identified as GVC-3 firms, only 5.8 percent of the firms qualify to fit the definition of GVC-4 compared to 28 and 15 percent fitting the definitions of GVC-1 and GVC-2.

Table 7 presents the results of our recursive bivariate probit estimates for alternative definitions of GVCs. From the table, we observe that the impact of both website adoption and access to highspeed internet connectivity is positive and significant across all specifications. Further, based on the marginal effects reported we can note that digitalization promotes GVC participation by 4–5 percent for GVC-3 firms and 3–5.5 percent for GVC-4 firms. These results, along with those for the control variables appear to be in line with the baseline estimates.

In our second set of robustness checks, we use the firm's ability to use email (E-Mail)²² to communicate with its clients or suppliers as an alternate proxy for digitalization. This variable captures the firms' use of information and communication services via a binary variable that takes the value 1 if a firm uses an e-mail to communicate with a client or a supplier. In a recent study,

²² The information on E-mail similar to website adoption is available for 52 economies over 2006–2018.

Table 7
Alternative Definitions of GVCs.

	(1) GVC-3	(2) GVC-4	(3) GVC-3	(4) GVC-4
Website	0.0629*** (0.00915)	0.0503*** (0.00856)		
Highspeed			0.163*** (0.0465)	0.164*** (0.0463)
Ln Size	0.0280*** (0.00118)	0.0220*** (0.000997)	0.0387*** (0.00318)	0.0318*** (0.00275)
Ln Productivity	0.00824*** (0.000858)	0.00728*** (0.000767)	0.00692*** (0.00192)	0.00685*** (0.00164)
Ln Age	0.00256 (0.00239)	0.00864*** (0.00212)	0.0210** (0.00850)	0.0277*** (0.00725)
Foreign	0.0472*** (0.00306)	0.0351*** (0.00257)	0.118*** (0.00977)	0.0882*** (0.00814)
Sole	-0.0189*** (0.00391)	-0.0110*** (0.00356)	-0.0347* (0.0178)	-0.0208 (0.0162)
First Stage				
Website_Mean	0.0471*** (0.00354)	0.0301*** (0.00333)		
Highspeed_Mean			0.0442*** (0.0126)	0.0341*** (0.0126)
Year Dummy	Yes	Yes	Yes	Yes
Industry Dummy	Yes	Yes	Yes	Yes
Country Dummy	Yes	Yes	Yes	Yes
Observations	24,352	24,352	4916	4916

Notes:
 1. GVC-3 is defined as two-way trading firms that use technology licensed by a foreign owned company.
 2. GVC-4 is defined as two-way trading firms that use technology licensed by a foreign owned company and also have an internationally recognized quality certification.
 3. All columns report the marginal effects.
 4. The proxy for digitalization is the use of Website and access to Highspeed internet connectivity.
 5. Standard errors are in parenthesis.
 6. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Lederman and Pena (2020) proxy firm digital adoption using email and document a 1.6 percent productivity premium for firms using email in their business activities. In this regard, we regress the email variable on four different metrics of GVC proposed in the paper. Table 8 reveals a significant and positive association of email service usage and GVC integration of the firms. In terms of the magnitude, we observe that for a one standard deviation increase in use of email services, increases the probability of GVC (GVC-1) participation by 4.1 percent, 2.5 percent for GVC-2, 2.3 percent for GVC-3 and by 1.2 percent for GVC-4 firms. The results of the controls are also in line with the existing literature.

Next, we carry out a variety of sub-sample analysis and show some empirical extensions. First, we start with disentangling the differential impact of digitalization on GVC participation across firms belonging to big and small agglomerates. There exists an extensive literature that suggests how clustering of firms leads to increased labor pool availability, knowledge spillovers, formation of dense local networks, and reduced shipping costs, which in totality present firms from big agglomerates an advantage over other firms (Marshall, 1920; Giuliani et al., 2005; Rice et al., 2006). However, a growing body of competing literature empirically established that internet adoption by firms, through reducing the costs associated with coordinating economic activities across geographical areas (Forman et al., 2005; 2012), could reduce the potential advantages of co-locating and consequently yield greater benefits for firms from smaller agglomerates (Paunov and Rollo, 2016).

To investigate which of these competing effects dominate in our GVC participation-digitalization nexus, we incorporate agglomeration as a binary variable in our analysis where big agglomerate is a firm operating in a capital city or a city with more than 1 million residents, and 0 otherwise. Table A4 presents the results of our

Table 8
Alternative Indicator of Digitalization.

	(1) GVC-1	(2) GVC-2	(3) GVC-3	(4) GVC-4
Email	0.222*** (0.0230)	0.111*** (0.0288)	0.0641*** (0.0189)	0.0373* (0.0195)
Ln Size	0.0902*** (0.00166)	0.0667*** (0.00153)	0.0352*** (0.00127)	0.0285*** (0.00113)
Ln Productivity	0.0218*** (0.00167)	0.0219*** (0.00147)	0.00183*** (0.000609)	0.00253*** (0.000501)
Ln Age	0.0196*** (0.00466)	0.0317*** (0.00390)	0.00762** (0.00332)	0.0129*** (0.00273)
Foreign	0.128*** (0.00682)	0.0718*** (0.00530)	0.0762*** (0.00397)	0.0502*** (0.00325)
Sole	-0.0456*** (0.00666)	-0.0375*** (0.00648)	-0.0282*** (0.00538)	-0.0187*** (0.00470)
First Stage				
Email_Mean	0.0955*** (0.00682)	0.0308*** (0.00548)	0.0169*** (0.00328)	0.00839*** (0.00262)
Year Dummy	Yes	Yes	Yes	Yes
Industry Dummy	Yes	Yes	Yes	Yes
Country Dummy	Yes	Yes	Yes	Yes
Observations	24,352	24,352	24,352	24,352

Notes:.

1. All columns report the marginal effects.
2. The proxy for digitalization is the use of E-Mail.
3. Standard errors are in parenthesis.
4. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

empirical analysis.²³ We find that digitalization has a positive and significant impact on driving GVC participation of firms from both big and small agglomerates, which point that gains through digitalization in terms of GVC integration are not restricted to firms from large agglomerates alone.

In our next sub-sample analysis, we account for the differences in firm size and re-estimate the relationship between digitalization and firms' GVC participation. The underlying rationale stems from the related literature that shows how large firms are less financially constrained and thus more likely to adopt new technologies early (Haller and Siedschlag, 2011). Within this frame of reference, Hagsten and Kotnik (2017) highlight that ICT capabilities acts as a significant facilitator of internationalization among SMEs from 12 European countries. A recent IMF (2020) study finds extent of digitalization to be more among larger and experienced firms. In order to highlight the importance of digitalization for SMEs, we re-estimate Eq. (1) for a sub-sample of firms focusing on SMEs only.²⁴ Table A5 reports the results. As we can observe, across all the measures of GVCs, the impact of digitalization is positive and significant for SMEs. These findings highlight the importance of technological adoption, especially for SMEs to become suppliers of parts and components in GVCs.

Finally, we undertake a panel analysis for a smaller subset of economies that can be constructed using the WBES database. It is worth recalling that the WBES surveys are carried out at different time intervals and the unique firm identifiers employed in each round of survey make it difficult to construct a firm-level panel data. Notwithstanding this limitation, we attempt to construct a small firm-level panel that is available only for 21 economies corresponding to 4486 firm-year observations. An additional caveat of this panel is that countries captured in the sample do not include several emerging economies that have been experiencing an increase in GVC participation over time (such as China and other

²³ The results with highspeed variable as the focal explanatory variable are qualitatively similar and are not reported for brevity.

²⁴ Following the WBES survey methodology, a small firm employs less than 20 workers, while a medium firm employs 20-99 employees. For more, see <https://www.enterprisesurveys.org/en/methodology>.

major Asian economies, for example). On the other hand, the panel is represented more heavily by countries in the South American region.²⁵ Nevertheless, we still make use of the panel data to revisit the digitalization-GVC nexus to add another layer of robustness. The results of this analysis²⁶ are shown in Table A6. As the results show, we observe that similar to our baseline estimates, website adoption and access to highspeed internet has a positive and significant association on GVC participation of the firms. The coefficients reported in Table A6 are marginal effects, implying that digitalization increases the probability of a firm participating in GVC by 6–11 percent. We also note that the results of the control variables are similar to the baselines estimates and in line with the existing literature.

4. Conclusion, limitations and future research directions

In this study, we have attempted to contribute to the literature by understanding the empirical association between digitalization and global value chains. We empirically address a simple but crucial question: does digitalization by firms spur their participation in global value chains (GVCs)? We have dealt with this relationship between digitalization of firms and their participation in GVCs by using firm-level data for a sample of 24,839 firms across 52 emerging and developing economies spanning the period 2006–2018.

After correcting for potential biases arising from self-selection and reverse causality, our empirical findings show that digitalization attempts by firms positively influence their GVC participation. Specifically, we find that firms adopting digitalization through the use of high-speed internet and website adoption are 6–10 percent more likely to participate in GVCs, which is economically quite significant. Our empirical results also offer evidence in favor of SMEs benefitting from greater digitalization, a useful result from policy perspective. We also highlight the significance of digitalization for financially constrained firms endeavoring to participate in global production chains. Finally, we also find that internet adoption promotes GVC participation of firms from small agglomerates. Overall, our results appear robust to alternative definitions of both GVCs and digitalization.

Despite multiple measures employed as sensitivity checks and the robust nature of our results, our study is not free from limitations. First, while identifying GVC firms, an important subset of the firms, which hold special relevance for EMDEs are SMEs that partake in GVCs via the indirect channel. These firms are often suppliers to large firms which in turn participate in GVCs and hence accounting for this indirect channel is an important aspect of GVCs. However, the lack of data does not allow us to identify these firms' participation in GVCs via the indirect channel, a limitation if overcome can be a promising avenue for future research.

Second, though our metric of GVCs is in line with the rapidly expanding literature, the absence of granular data identifying the source and use of inputs restricts us from constructing finer measures of GVCs. Availability of such data at the firm-level for EMDEs can pave the way for exploring these questions in more detail, something that future research studies can explore.

Finally, along similar lines, the availability of information on intricate aspects of digitalization such as usage of ICT for various in-

²⁵ List of countries (observations) available in the panel database: Argentina (850); Benin (54); Bolivia (127); Burkina Faso (68); Cameroon (142); Cote D'Ivoire (56); Ecuador (124); Honduras (50); Kenya (56); Lao PDR (64); Liberia (72); Mali (224); Myanmar (254); Nicaragua (179); Paraguay (125); Peru (698); Sierra Leone (64); Turkey (506); Uruguay (256); Zimbabwe (290)

²⁶ In our panel estimation, we are unable to incorporate firm fixed effects due to convergence issues. For more on the problem of convergence in panel data estimation, see Kiviet (2020).

house activities such as warehouse management, or advanced information processing tools and other supply chain related aspects could prove to be instrumental in unpacking the impact of digitalization of firms on their participation in GVCs.

Declaration of Competing Interest

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

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.infoecopol.2022.100972.

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