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Telecommunications submarine cable vulnerability and local performance of firms in developing and transition countries

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Abstract

We estimate the impact of Internet diffusion on local firm performance in developing and transition economies, by adopting an instrumental variable approach reflecting firm's vulnerability to seismic shocks upon the telecommunications submarine cable (SMC) network. IV within fixed-effect estimations are conducted at the location-level, based on an original sample of some 30,000 firms from 125 locations in around 40 developing and transition countries. Results point to large and positive local impacts of a greater Internet diffusion among firms, induced by lower digital vulnerability, on their average revenue, labour productivity, and employment. … /…

Keywords: ICT, Internet, submarine cables, infrastructures, telecommunications, firm performance

JEL codes: F02, O11, O33, O18, L25, L96

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… /… These impacts are found to be larger for domestic SMEs, and partly driven by service firms. Moreover, a greater use of Internet is found to increase the number of production workers more than non-production workers in manufactures. This difference seems mostly explained by the large positive effect of internet use on the unskilled production workforce.

1- Introduction

Over the last few decades, international connectivity underwent a dramatic improvement promoted by the laying of 321 fibre submarine cables (SMCs) over 1990–2015. Today, more than 99% of the world's telecommunications – Internet content, phone and video calls, classified diplomatic messages – pass through SMCs that irrigate a USD 20.4 trillion industry and connect 3 billion Internet users across the world (Towela & Tesfaye, 2015). In 2013, according to the OECD (Weller & Woodcock, 2013), "20 households with average broadband usage generate as much traffic as the entire Internet carried in 1995".

Almost all coastal developing and transition countries have access to the global Internet through SMCs. Fast-growing Asian and South American countries have been rapidly connected to Northern economies, while Africa's digital isolation from the rest of the world has rapidly fallen since 2009 (Cariolle, 2018). This massive deployment of the international broadband infrastructure network has stimulated the telecommunications sector worldwide (Graph 1), and raised strong expectations for many low-income countries' economic catch-up, notably, through its potential for fostering innovation, productivity, trade, and job creation.

In the 2000s, a first strand of the literature started to study the macro-level effect of Internet penetration rates on international trade, in the wake of the "Internet bubble" and the financial collapse that followed. These studies generally find a positive effect of improved Internet access on trade in developing countries (Freund & Weinhold, 2004; Clarke & Wallsten, 2006), more specifically, service exports (Freund & Weinhold, 2002; Choi, 2010). Other macro-level studies have pointed out the broad contribution of Internet access to productivity and growth (Cette et al., 2015; Niebel, 2018). For instance, Röller and Waverman (2001) evidence a causal relationship between telecommunication infrastructures and GDP for a sample of 21 OECD countries, stressing the important externalities yielded by this type of infrastructures. Assuming that the Internet can facilitate knowledge spillovers, Choi and Yi (2009) show that Internet penetration contributes to economic growth. Examining the impact of higher broadband penetration rates in 25 OECD countries, Czernich et al. (2011) get comparable results.

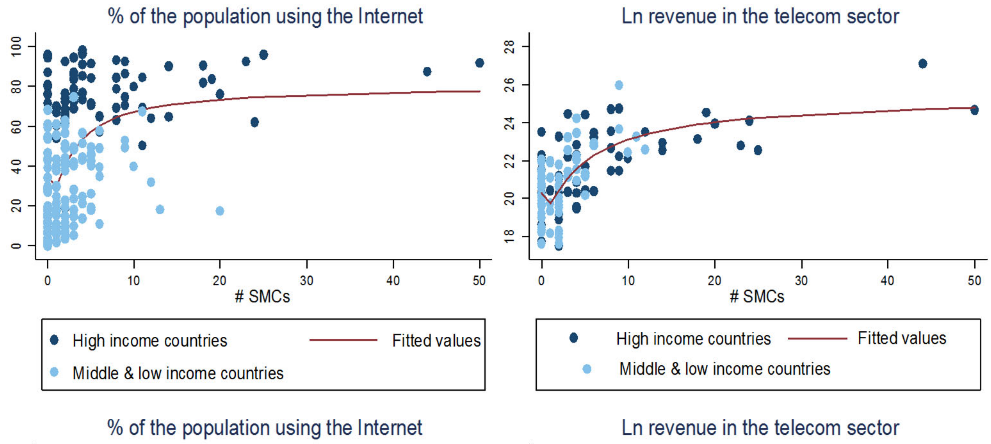
More recent studies have focused on the micro-level effects of Internet access and usage on firms' outcomes, especially productivity and exports. Regarding productivity, various recent studies have stressed that ICT adoption and usage lead to increase in firms' factors productivity.[1] Clarke et al. (2015) show that Internet use increases firms' sales growth and labour productivity, particularly in the case of small firms. In this line of research, Paunov and Rollo (2015) find that, in 117 developing countries, the intensity of Internet use at the industry level has a significant and positive effect on labour productivity, especially in the most productive firms of the sample. Regarding the extensive margin, Clarke (2008) finds that the use of the Internet by firms in

[1] For a review of these contributions, see Goldfarb and Tucker (2019).

Eastern Europe and Central Asia has a significant impact on their decision to export, but no effect on their intensive margin. More recently, Hjort and Poulsen (2019) show that improved access to broadband Internet following SMC laying in Africa has stimulated job creation, by increasing firms' entry, exports and productivity.

Although non-exhaustive, this short review of the literature points to a positive macro-level effect of Internet diffusion on trade and growth in developing countries, supported at the micro-level by evidence on the growth in firms' productivity and exports.

Graph 1. Correlation between SMC deployment and the Internet economy, worldwide evidence in 2014



Notes: Data on infrastructure deployment are drawn from Telegeography. Data on Internet penetration and revenue are drawn from the International Telecommunication Union (2016). **Sample:** share of population using Internet variable: 201 developed countries (dark blue) and developing countries (light blue). Telecommunications revenue variable: 122 developed and developing countries.

This paper brings additional insights into this line of research by providing new evidence on the local impact of improved access to Internet on four firm outcomes – their total revenue, their labour productivity, their exports, the size and the composition of their workforce – in a baseline sample of 38 developing and transition countries. In particular, the main novelty of this paper lies in its instrumental variable approach, emphasizing a new vulnerability related to SMC deployment: the SMC network's exposure to seismic risk.

In fact, countries' high dependence on SMCs for international telecommunications has increased their vulnerability to SMC faults. Among the natural causes of SMC outages, maritime seismic events are known to be a serious threat to the SMC network integrity (Carter et al. 2009, 2014). Seaquakes indeed represent a major cause of multiple SMC wear or breaks, by shaking violently the underwater body, provoking turbidity currents, landslides, and seabed sand waves (Soh et al, 2004; Carter et al, 2009; Clark, 2016; Aceto et al, 2018; Yincan et al, 2018). Within countries, firms' vulnerability to SMC faults will differ according to their distance to key telecommunication infrastructures. There is indeed a vast literature showing that digitally isolated populations, i.e. remote from key infrastructures, are more exposed to telecommunication network disruptions (Malecki, 2002; Grubesic and Murray, 2006; Grubesic et al., 2003; Gorman et al., 2004; Buys et al., 2009; Cariolle, 2018).

Our instrument set combines two dimensions of digital vulnerability: the country exposure to external shocks and the firm exposure to telecommunications disruptions. Instrumental variables therefore consist in combining a variable equal to the annual frequency of seaquakes located in the vicinity of SMC landing stations, weighted by the firm locations' distance to the closest key infrastructure nodes (SMC landing stations or Internet exchange points). The empirical analysis is conducted using data from the World Bank Enterprise Surveys on more than 30,000 firms, located in around 125 locations in some 38 developing and transition countries. To avoid network or spillover effect of Internet use among firms and to control for omitted variable bias, the instrumental variable framework is applied to a pseudo panel, based on firm-level data aggregated by locations (municipality or province), controlling for country, year, country-year, sector and location fixed effects.

Consistent with the view that the telecommunications infrastructure has important local spillovers and/or network externalities (Litan & Rivlin, 2001; Röller & Waverman, 2001; Bjorkegren, 2019; Goldfarb & Tucker, 2019), this paper emphasizes the large effects of Internet diffusion on firm performance at the location level, and therefore, suggests that the impact of access to broadband is heterogeneous within countries. In fact, IV estimations stress that a lower digital vulnerability fosters Internet use among firms and so boosts their revenue, labour productivity and employment. We do not find such evidence on the firms' share of exports, and results appear to be driven by service firms rather than manufactures. This evidence is robust to a range of restrictions upon the sample and the instrument set calibration, meant to address reverse causality, measurement error and omitted variable biases. Moreover, using more detailed employment data provided by firms from the manufacture sector, we find in a consistent way, and in support of recent evidence (Hjort & Poulsen, 2019), a strong positive effect of email use on the number of production workers. This evidence seems to be driven by a large increase in the number of unskilled production workers.

Our paper is organized as follows. In the next section we present our data and some descriptive statistics. In the third section, we explain our identification strategy. The fourth section presents the main results and the last one concludes.

2- Model and Data

2.1. Model

We estimate the following general model:

$$Y_{j,l,t} = \alpha_0 + \alpha_1 Internet_{j,l,t} + \alpha_2 X_{j,l,t} + \gamma_j + \delta_t + (\gamma_j \times \delta_t) + \theta_l + \vartheta_r + \varepsilon_{j,l,t} \quad (1)$$

Where the subscripts *j, l, r, t* respectively refer to the country, the location, the region, and the survey year. Locations are therefore the observation units. $Y_{j,l,t}$, $Internet_{j,l,t}$, and $X_{j,l,t}$ are respectively the average firm's performance, the share of firm using Internet, and average firm's characteristics in locations. Firm's characteristics include the number of full time permanent employees when the firm has started operations, the firm's age, the ownership structure (state and foreign ownership), the share of direct and indirect exports (only indirect exports when the dependent variable is the share of direct exports), the firm's industry, and the frequency of power outages. $\varepsilon_{l,t}$ is a random error term. We also control for country (γ_j), year (δ_t), country-year ($\gamma_j \times \delta_t$), region (ϑ_r), and location (θ_l) fixed effects.

2.2. The data

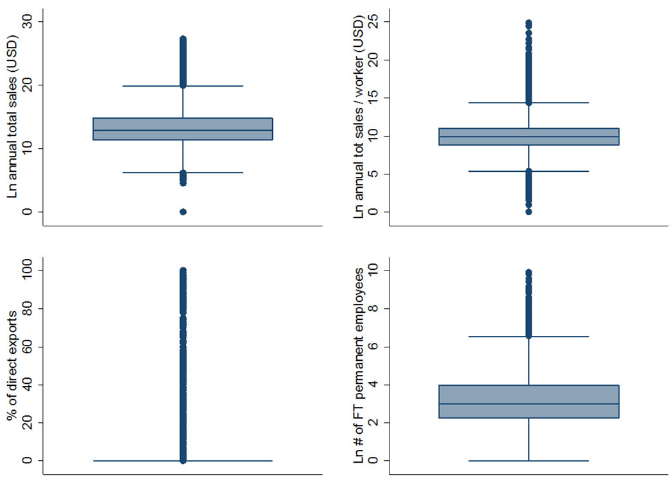
All firm-level variables used in our model are drawn from the World Bank Enterprise Survey (WBES) harmonized cross-sectional dataset. Data sources and summary statistics are reported in appendix A. These surveys cover a representative sample of a formal economy's manufacturing and service sectors. In each country, data were gathered by an extensive and internationally comparable questionnaire administered by face-to-face interviews with business owners and senior managers.

To estimate the effect of the use of Internet by firms on their performance, we build a pseudo panel by aggregating firm level data by location (i.e. municipality or province) and by survey year, and keeping locations where firms have been at least twice surveyed. This strategy allows us to: i) conduct within fixed-effect IV estimations, and therefore to control for unobserved time-invariant heterogeneity at the location level[2], and ii) to control for local network externalities and/or spillovers (Röller & Waverman, 2001; Bjorkegren, 2019; Goldfarb and Tucker, 2019), by aggregating at the location-level firm's characteristics and outcomes.

2.2.1. Dependant variables ($Y_{j,l,t}$)

To measure individual firm performance, we alternatively use the logarithms of firm's total annual sales and sales per full-time employee (both converted into USD), the share of direct exports in total sales, and the logarithm of the number of permanent full-time employees. Graphs 2 and 3 plot these variables' distribution at the firm and location levels, respectively. We also further study the Internet-employment nexus by looking at the effect of Internet use by manufactures on their number of production and non-production workers, and on the number of skilled and unskilled production workers. Appendix A.1 reports summary statistics of these variables.

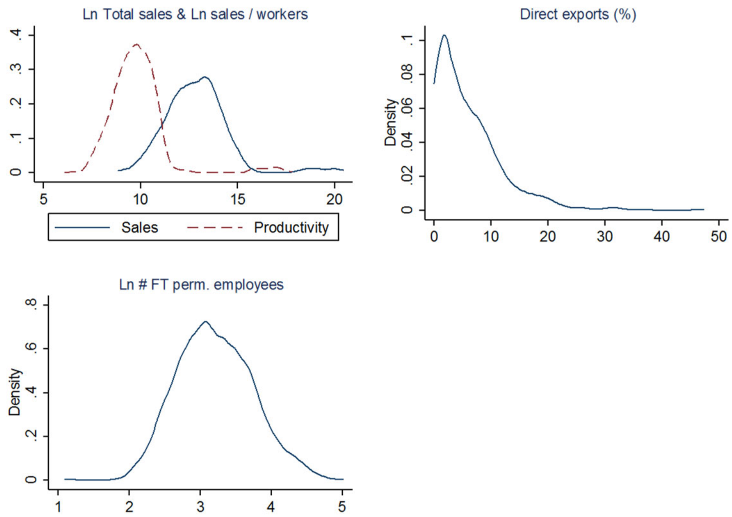
Graph 2. Distributions of firm outcomes, firm-level data before aggregation



Data: World Bank Enterprise Surveys.

[2] The design of the survey is initially not suited for panel data analysis because of missing panel ID.

Graph 3. Kernel densities of firm outcomes, location-level data after aggregation

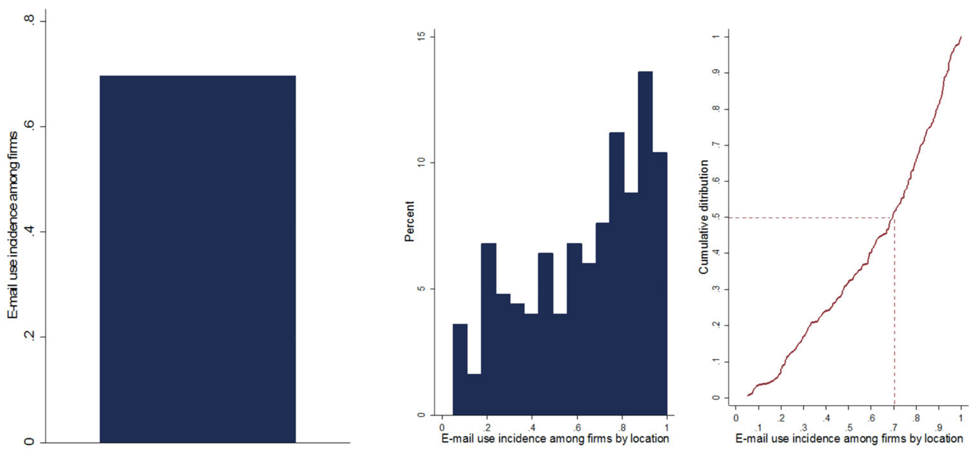


Data: World Bank Enterprise Survey.

2.2.2. Variable of interest (Internet$_{j,l,t}$)

Our variable of interest is a dummy variable equal to one if the firm i declares using emails to communicate with its clients and suppliers at the time of the survey, drawn from the World Bank Enterprise Surveys. At the location level, this variable represents the incidence of internet use among firms, expressed as a share of firms. This variable is our main variable of interest because email is the most basic way to use Internet, reflecting both simple and more complex usages of the Internet. Graphs 4 below give some insights into firms' reported experience of Internet use. The left-hand side graph shows that around 70% of firms of the sample have reported using email during their operations. After data aggregation at the location level, we get a continuous variable which distributions (middle and right-hand side graphs) stress that half of locations display Internet penetration rates among firms exceeding 70%, while the other half of locations have Internet penetration rates lying between 5% and 70%.

Graph 4. Global and local incidence of Internet use among firms



Data: World Bank Enterprise Surveys. Sample: 32,098 firms, 125 locations, 38 countries. Data averaged at the location-level in the middle and right-hand side graphs.

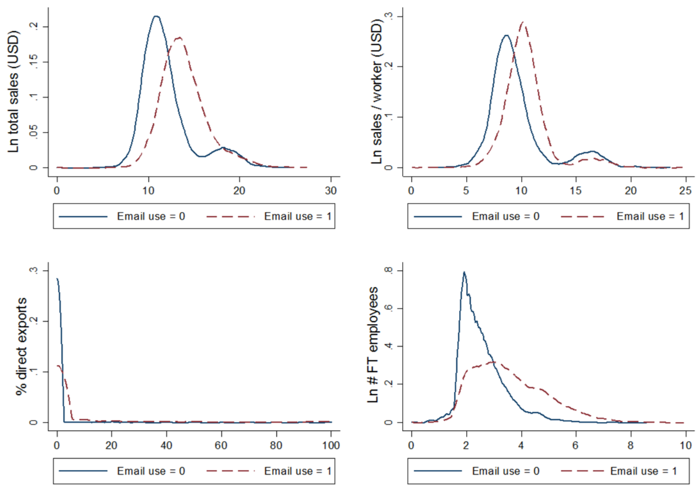
2.3. Descriptive statistics

Our sample mostly consist of firms located in sub-Saharan Africa (24% of firms and locations), Eastern-Europe and Central Asia (43% of locations representing 31% of firms,), and Latin-America (22% of locations representing 38% of firms). Locations are in average composed of 55.6% of service firms, mostly operating in retail and wholesale trade (31%), in the food (12%), in other service (10.2%) and other manufacturing industries (8.6%). Appendix A provides further statistics on the sample composition.

A quick look at graph 5 suggests some differences in economic performances between firms using Internet and those which do not. In fact, those using Internet seem to have higher annual sales and higher labour productivity, on average. However, such differences are not observable in terms of direct export share, and employment.

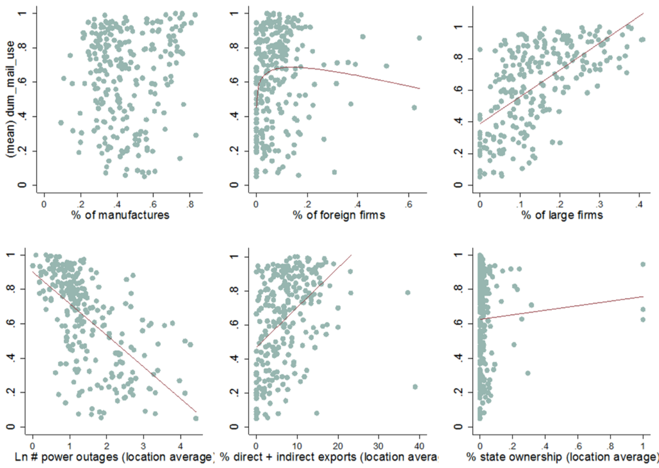
Looking at the firm determinants of email use, data aggregated at the location level provides us with interesting insights into the relationship between firm characteristics and email use incidence at the location level. In fact, graphical correlations depicted in graph 6 suggests that locations with a higher proportion of large firms and a higher share of firm exports (indirect and direct) are associated with a higher incidence of email use during operations. By contrast, locations subjects to a larger number of power outage are associated with a lower incidence of email use. A positive but weaker relationship between state ownership or the prevalence of foreign firms on the one hand, and email use y firms on the other, is also observable. We see, at first sight, no clear relationship between the share of manufactures and email use incidence at the location level.

Graph 5. Firm outcomes & Internet use.



Data: World Bank Enterprise Surveys. Sample: 250 observations (125 locations, 38 countries) from an original sample of 32,098 firms.

Graph 6. Firm characteristics & Internet use.



Data: World Bank Enterprise Surveys. Sample: 250 observations (125 locations, 38 countries) from an original sample of 32,098 firms.

3- Identification strategy

To study the effect of Internet use on the performance of firms, the main issue is the possible endogeneity bias, induced by location selection, omitted variables, and/or reverse causality. To address the selection and omitted variable biases, we apply the within fixed-effect estimator to equation (1) that allows controlling for location time-invariant unobserved heterogeneity that could explain firms' location choice and inclination to use Internet. We also include country, year, country-year, and region dummies to control for higher-level unobserved characteristics. To address an eventual simultaneity bias between Internet use and firm performance, we apply the fixed-effect two-stage least square estimator (FE-2SLS), which adds the following first-stage equation to equation (1):

$$Internet_{j,l,t} = \beta_0 + \beta_1 Instruments_{l,t} + \beta_2 X_{j,l,t} + \gamma_j + \delta_t + (\gamma_j \times \delta_t) + \theta_l + \vartheta_r + \varepsilon_{j,l,t} \quad (2)$$

where the subscripts have the same meaning as in eq. (1). Control variables and fixed effects are the same as those specified in eq. (1). The $Instruments_{j,l,t}$ vector corresponds to instrumental variables described in the next sub-sections. The identification strategy underlying the instrument set provides an answer to the following question: what happens to firms when the SMC network's integrity is threatened? It therefore combines an external source with an internal source of digital vulnerability, that is, the SMC network exposure to seismic risk with the location distance to key infrastructure nodes.

3.1. Deployment of telecommunication infrastructures and digital vulnerability

During the last decades, the progressive deployment of SMCs connecting countries to the global Internet has boosted the Internet economy worldwide, by affecting the total bandwidth available to Internet users, the cost of Internet services, the competition environment, and the Internet stability (Weller & Woodcock, 2013; Schumann & Kende, 2013; Telegeography, 2016). In absence of SMCs, a country has two solutions to get international Internet connection: (i) buying expensive and limited Internet bandwidth from a SMC-connected neighbouring country or (ii) buying expensive, often slow and limited Internet bandwidth from telecommunications satellites.[3] The laying of SMC infrastructures is therefore indispensable to get access to a fast, stable and affordable access to international telecommunications.

However, SMC deployment has also increased countries' vulnerability to SMC faults (Aceto et al, 2018; Cariolle, 2018), especially those relying on a few SMCs. SMC faults induce large costs for operators owning these cables, amounting to millions of dollars, related to repair and insurance costs. There are also large indirect costs related to i) the reporting of repair and insurance costs on Internet tariffs; ii) the rerouting of Internet traffic towards more expensive cable paths, with limited available bandwidth; and iii) the disorganization of global manufacturing chains and Internet-related service provision (Widmer et al., 2010; Clark, 2016; Aceto et al., 2018). Last but not least, these indirect costs are amplified by delays necessary for cable repairs.[4]

The main causes of SMC outages can be classified in two broad categories (Carter et al, 2009; Clark, 2016): i) human activities, mainly maritime activities (fishing nets, anchors), the most common cause of outages, but also acts of piracy and sabotage; and ii) natural events, such as seismic events, typhoons, floods, volcanic eruptions and turbidity currents, which are the main cause of simultaneous, multiple, and therefore costlier SMC faults. Our identification strategy is focused on one important external source of digital vulnerability: the maritime seismic activity.

3.2. Seismic risk and digital vulnerability

By generating turbidity, landslides, and tsunamis (Soh et al., 2004; Carter et al., 2009; Clark, 2016, Aceto et al., 2018; Carter et al., 2014), seaquakes represent a major cause of direct or indirect cable breaks. As an illustration of severe damages caused by tectonic activity on fibre submarine cables, we can mention the 2011 Tohoku earthquake that affected Japanese coastlines in 2011 and resulted in about 20 cable cuts on six different SMCs. The international broadband network is also regularly impacted by frequent earthquakes that strike the region of Taiwan, where several submarine cables are laid. As an example, the 2006 earthquake caused 18 cable cuts on 8 SMCs, interrupting Internet and phone communications in Taiwan, Singapore, Hong Kong, South Korea and Japan and causing major disturbances on telecommunications in other parts of the world.[5] Beyond these spectacular examples of large-magnitude seismic events, the redundancy of lower-magnitude seismic activity in the vicinity of SMCs contribute to damage or erode entire sections of the cable network SMCs and to destabilize the seabed into which cables are buried, affecting the likelihood of future faults, and thereby, their capacity to transmit international communications.

We exploit information on the location, timing, frequency, and magnitude of seaquakes to build, at country level, a variable of *seismic risk exposure*: the annual frequency of seaquakes likely to affect the functioning of SMCs. In fact, because seismic activity may cause damages to the whole economy and not only to the SMC network, our identification strategy focuses on the occurrence of seaquake, and therefore exclude earthquakes from the analysis.[6] Moreover, to respect identification restrictions, we only consider medium-magnitude seaquakes, which epicentres are

[3] Although the provision of new broadband Internet services by satellite is growing but yet non-competitive.

[4] According to Palmer-Felgate et al. (2013), these delays vary significantly among maintenance areas (see appendix E.3) and countries, and are lengthened by multiple outages, caused by natural events such as earthquakes or typhoons, by ships engaged in prior repairs (likely induced by multiple outages), by repair permit acquisition delay, or by other operational issues (Borland, 2008).

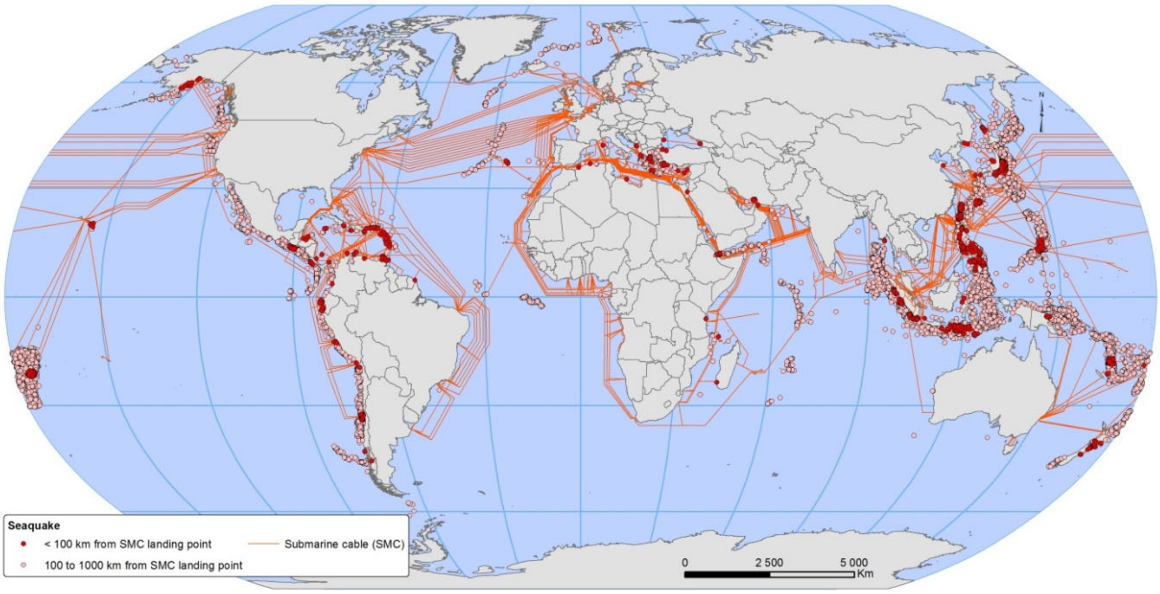
[5] The New-York Time, December 27th, 2006.

[6] The inclusion of region, country and country-year fixed effects in our estimates also allows controlling for all specific shocks affecting the economies.

located within a 100-1000km radius from the SMC landing station. First, we only count seaquakes with intensity above 5 on the Richter scale, and drop observations associated with seaquakes which magnitude is above 6.5: below 5, the seaquake might have little effect on the SMC infrastructure, while above 6.5 the seaquake may damage coastal areas.[7] Second, seaquakes located within a 100km a radius from SMC landing stations, despite their medium magnitude, could eventually damage the littoral, while seaquakes located beyond a 1000km radius may have little effect on SMCs[8]. This instrument calibration is therefore meant to ensure that considered seismic events affect SMCs but not the rest of the economy.

To illustrate the world infrastructure's exposure to seismic risk, Figure 1 below maps worldwide seismic events which epicentre is located within a 100 and 1000km radius from SMC landing stations, from 2005 to 2017. Seismic events depicted in light-pink dots are those considered in the analysis.

Figure 1. International seismic activity - between 5 and 6.5 on Richter scale within a 100 or 1000km radius from SMC landing stations, 2005-2017.



Sources: Authors. Raw data: Telegeography and Northern California Earthquake Data Center of the University of California, Berkeley.

3.3. Digital isolation and digital vulnerability.

Grubesic and Murray (2006) and Grubesic et al (2003) stress that, when telecommunication assets are geographically concentrated, locations distant from telecommunication nodes, i.e. inland, rural and isolated locations, are particularly exposed to telecommunication disruptions, and are slower to recover after telecommunication shutdowns (see also Gorman and Malecki, 2000; Gorman et al., 2004). In support of this finding, Cariolle (2018) shows that, in a panel of

[7] The lower bound has been chosen according to the work of Soh et al. (2004), who find that cable breaks occurred in the eastern part of Taiwan following earthquakes ranging from 5.0 to 6.0 on the Richter scale. The upper bound is based on interviews with Dr Raphaël Paris, Research Officer in volcanology at CNRS and Laboratoire Magmas et Volcans (LMV) (Observatoire de Physique du Globe de Clermont-Ferrand, Clermont-Auvergne University), who pointed out that the risk of tsunami becomes significant with seismic activity above 6.5 on the Richter scale.
[8] Information on precise SMC paths is not available.

sub-Saharan African countries, the average population distance to SMC landing stations increases fixed phone-line fault frequency, and reduces Internet penetration rates.

To make our instruments vary at the location level, and taking the fact that being geographically remote from broadband nodes increase the likelihood of telecommunications disruptions (see graph 2), we weight our seaquake variable by the geographical distance of firms' locations to the closest SMC landing station or Internet Exchange Point (IXP).[9] With SMC landing stations, IXPs represent a key element of national and regional backbone telecommunications infrastructures and an important source of network efficiency and Internet bandwidth (Weller & Woodcock, 2013; OECD, 2014; Towela & Tesfaye, 2015). IXPs are indeed telecommunication hubs favouring direct interconnections between countries, and enhancing the telecommunication network efficiency and capacity by keeping local traffic locally, national traffic nationally, regional traffic regionally, and international traffic internationally. By doing this, IXPs also make it possible to carry Internet traffic at low cost, which reduces the cost of providing access to Internet. Therefore, IXPs increase Internet performance and cost-efficiency and are hence a central element of local and regional Internet ecosystems (Weller & Woodcock, 2013; OECD, 2014).

3.4. Instrument set

Our instrument therefore consists in combining a variable of seismic risk exposure, respecting the constraints detailed in subsection 3.2, with a variable of location distance (in km, logarithm) to infrastructures nodes (either SMC landing station, or IXPs):

$$Instrument_{l,t} = Seaquake\ frequency\ \times (ln) location\ distance\ to\ infrastructure\ nodes \qquad (3)$$

This instrument is then decomposed into two sub-instruments, using the seaquake frequency variable computed according to different radiuses from SMC landing stations – 100-500km and 500-1000km – to account for possible nonlinearities in the impact of seaquakes depending on their distance to SMC landing stations.

4- Results

4.1. Baseline estimations

Results of FE-2SLS estimates are reported in Table 1. They support that the use of email during firms' operations is positively and significantly associated with firms' total sales, productivity and employment. According to these estimates, a 10% increase in email use is significantly associated with a 37% increase in firms' sales, a 26% increase in labour productivity and a 12% increase in the number of permanent employees. However, we do not find evidence of a significant effect of email use on firm exports. Estimates reported in table 2 show that these relationships hold after the exclusion of outliers from the sample.

[9] While information on terrestrial backbone infrastructure deployment is not available for all developing and transition countries, the location of SMC landing stations and Internet Exchange Points (IXPs) is available for most of them. The distance variable is therefore the gap between SMC landing station GPS coordinates and the municipality or province's geographic centroid coordinates where the firm has declared its activity. Special cases and data treatment are explained in Appendix B.

Table 1. Digital vulnerability, email use, and firm's performance – within IV baseline estimations.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Var dep:	(ln) Total sales		(ln) Sales per worker		(ln) # FT employees		% direct exports[a]	
Email use	**2.088****	**3.690*****	**2.176*****	**2.607*****	**0.305**	**1.156*****	**6.946**	**3.152**
	(0.849)	**(0.906)**	**(0.625)**	**(0.573)**	**(0.804)**	**(0.389)**	**(5.069)**	**(4.977)**
State-owned		2.236		2.011*		-0.413		-6.784
		(1.582)		(1.146)		(0.715)		(8.734)
Foreign		-3.192**		-2.685**		0.302		23.22**
		(1.591)		(1.048)		(0.535)		(9.983)
Age		0.374		-0.0951		0.579***		-6.593***
		(0.245)		(0.209)		(0.197)		(1.798)
# power outages		-0.456***		-0.289***		-0.0184		0.0230
		(0.150)		(0.111)		(0.039)		(0.903)
% of exports		0.0298***		0.0153		0.007*		-0.157
		(0.00823)		(0.0105)		(0.003)		(0.184)
Initial # of FT employee		0.358***		0.221		0.0155		0.435
		(0.138)		(0.141)		(0.0780)		(1.530)
First stage estimates								
Seaquake freq 100-500km x Ln dist infra	-0.0022***	-0.0026***	-0.0022***	-0.0026***	-0.0021***	-0.0025***	-0.0022***	-0.0025***
	(0.0004)	(0.0005)	(0.0004)	(0.0005)	(0.0004)	(0.0005)	(0.0004)	(0.0005)
Seaquake freq 500-1000km x Ln dist infra	-0.0031**	-0.0039***	-0.0031**	-0.0039***	-0.0027*	-0.0039***	-0.0027*	-0.0039***
	(0.0016)	(0.0014)	(0.0016)	(0.0014)	(0.0014)	(0.0014)	(0.0014)	(0.0014)
Controls	No	Yes	No	Yes	No	Yes	No	Yes
Fixed effects	Country, year, country-year, sector, region, location							
Hansen test (p. value)	0.24	0.27	0.24	0.72	0.24	0.33	0.55	0.56
Weak-identification SW F-test	18.20***	17.81***	18.20***	17.81***	18.44***	17.81***	18.44***	14.98***
Underidentification SW Chi-sq.	48.31***	48.92***	48.31***	48.92***	48.74***	48.92***	48.74***	41.13***
N	273	251	273	251	289	251	289	251
# locations	136	125	136	125	144	125	144	125
# countries	41	38	41	38	44	38	44	38
# aggregated firms	43,539	32,178	43,539	32,178	46,408	32,178	46,408	32,178

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors are presented in parentheses, are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

Table 2. Digital vulnerability, email use, and firm performance, excluding outliers detected by the Grubbs test.

	(1)	(2)	(3)	(4)
Var dep:	**Total sales**	**Sales / worker**	**Direct exports[a]**	**# of FT employees**
Email use	**3.005***** **(0. 855)**	**2.201***** **(0.769)**	**5.093** **(4.672)**	**1.156***** **(0.388)**
1st stage est.				
Seaquake freq 100-500km x Ln dist infra	-0.0025*** (0.0006)	-0.0025*** (0.0006)	-0.0024*** (0.0005)	-0.0026*** (0.0006)
Seaquake freq 500-1000km x Ln dist infra	-0.0031*** (0.0014)	-0.0032*** (0.0014)	-0.0039*** (0.0015)	-0.0039*** (0.0014)
Fixed effects	Country, year, country-year, sector, region, location.			
Controls	Yes			
Hansen test p-value	0.81	0.43	0.70	0.33
Under-ident.. SW F-test	8.17***	8.15***	14.70***	17.81***
Weak indent. SW Chi-sq	22.69***	22.71***	40.47***	48.92***
N	233	231	249	251
# locations	116	115	124	125
# Countries	35	35	38	35

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors are presented in parentheses, are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

Whatever the model considered, identification statistics suggest that our instrument is relevant and valid, and first-stage estimates point to a negative, significant and consistent effect of SMC exposure to seismic events on the likelihood for firms of using Internet. This effect is found to be stronger when seaquakes are remote from the coast, confirming the observation of Carter et al (2009, 2014) according to which seismic events located in deep sea water are more detrimental SMC integrity than those closer to the coast.

In table 3, we decompose the sample between manufacturing and service firms, proceed to data aggregation using these two subsamples, and run separately previous econometric models to study whether estimated relationships depend on firms' sector of activity. Results stress that the effect of email use on total sales and employment is mainly driven by the service sector, but no difference between sectors is observable regarding the effect of email use on labour productivity.

Table 3. Digital vulnerability, email use, and firm's outcomes – within IV estimations, services vs. manufacturing sectors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Var dep:	**Sales**		**Sales/worker**		**Direct exports[a]**		**Ln # FT employees**	
	Manuf	**Services**	**Manuf**	**Services**	**Manuf**	**Services**	**Manuf**	**Services**
Email use	**-0.232**	**4.595*** **	**0.602**	**1.497**	**13.48**	**-0.445**	**0.398**	**1.497*** **
	(1.482)	**(1.157)**	**(0.910)**	**(0.935)**	**(8.381)**	**(9.168)**	**(0.710)**	**(0.482)**
First stage estimates:								
Seaquake freq 100-500km x Ln dist infra	-0.0025***	-0.0015***	-0.0025***	-0.0015***	-0.0025***	-0.0015***	-0.0015***	-0.0015***
	(0.0005)	(0.0004)	(0.0005)	(0.0004)	(0.0005)	(0.0004)	(0.0004)	(0.0004)
Seaquake freq 500-1000km x Ln dist infra	-0.0026	-0.0061***	-0.0026	-0.0061***	-0.0026	-0.0061***	-0.0061***	-0.0061***
	(0.0020)	(0.0014)	(0.0019)	(0.0014)	(0.0019)	(0.0014)	(0.0014)	(0.0014)
Controls	Yes							
Fixed effects	Country, year, country-year, sector, region, location							
Hansen test (p. value)	0.51	0.25	0.34	0.23	0.71	0.24	0.26	0.24
Under-ident.. SW F-test	10.33***	9.84***	10.33***	9.84***	10.33***	9.84***	10.33***	9.84***
Weak indent. SW Chi-sq	28.52***	26.73***	28.52***	26.73***	28.52***	26.73***	28.52***	26.73***
N	243	251	243	251	243	251	243	251
# locations	121	125	121	122	121	125	121	125
# Countries	38	38	38	38	38	38	38	38
# of aggregated firms	16,244	15,934	16,244	15,934	16,244	15,934	16,244	15,934

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors are presented in parentheses, are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

All in all, the increase in sales induced by Internet use by firms during operations can be explained by the increase in labour productivity, but not by a better access to foreign markets. Moreover, a higher penetration of Internet among firms is found to be beneficial to full-time permanent employment.

4.2. Robustness checks

First, to address an eventual location selection bias, we exclude from the sample large and foreign firms before data aggregation. These specific firms' location decisions could indeed be influenced by the presence of infrastructures, as they are known to be more geographically mobile (Dollar et al., 2006) than smaller or domestic firms. Moreover, large and foreign firms could be the main drivers of sales and productivity improvements, as evidenced by Van Biesebroeck (2005) in the African context. Results are presented in Table 4 and show a stronger and significant effect on domestic SMEs' total sales and sales per worker, and a less significant but still 10%-significant effect on FT employment.

Table 4. Digital vulnerability, email use, and firm performance, excluding large and foreign firms.

	(1)	(2)	(3)	(4)
Var dep:	**Total sales**	**Sales / worker**	**Direct exports[a]**	**# of FT employees**
Email use	**5.454*****	**3.921*****	**-1.884**	**0.608***
	(1.580)	**(1.117)**	**(9.915)**	**(0.338)**
1st stage est.				
Seaquake freq 100-500km x Ln dist infra	-0.0018**	-0.0018**	-0.0017**	-0.0026***
	(0.0008)	(0.0008)	(0.0008)	(0.0006)
Seaquake freq 500-1000km x Ln dist infra	-0.0046***	-0.0046*	-0.0044***	-0.0039***
	(0.0016)	(0.0016)	(0.0015)	(0.0014)
Fixed effects	Country, year, country-year, sector, region, location.			
Controls	Yes			
Hansen test p-value	0.66	0.44	0.71	0.42
Under-ident.. SW F-test	4.04**	4.04**	4.04**	4.04**
Weak indent. SW Chi-sq	10.98***	10.98***	10.99***	4.04***
N	251	251	251	251
# locations	125	125	125	125
# Countries	38	38	38	38

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors are presented in parentheses, are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

Second, even though seaquakes considered are of medium magnitude, and in average located between 200km and 1000km from the coast (graph 7), seaquakes located nearby the coast could indirectly affect Internet penetration rates by provoking physical or human casualties, and thereby make our instrument set invalid. Based on the distribution of the minimum annual seaquakes' distance to the coast in graph 7 (right-hand side graph), we impose a new constraint upon our sample consisting in excluding observations when this minimum distance is smaller than 50 km. Because this calibration induces observation attribution for the decomposed instrument set, we apply this restriction using a single (undecomposed) instrument, equal to the annual frequency of seaquakes located within a 500 km or a 1000km-radius from SMC landing station, separately. Results are reported in table 5 and are found to be robust to this additional constraint.

Graph 7. Average and minimum distances to the coast of seaquakes located within a 100-1000km radius from the landing station.

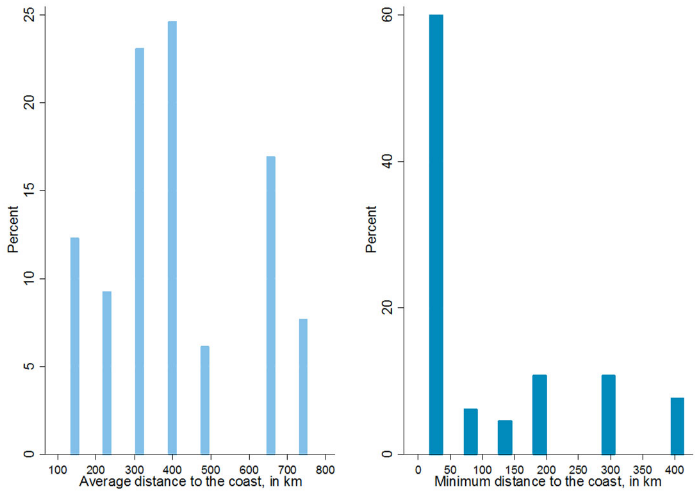


Table 5. Digital vulnerability, email use, and firm performance – excluding seaquakes close to the coast.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Var dep:	**Total sales**		**Sales / worker**		**Direct exports**		**# of FT employees**	
Email use	**2.276*** **	**2.617*** **	**2.014*** **	**2.306*** **	**9.799**	**11.751**	**1.203** **	**1.141** **
	(0.873)	**(0.769)**	**(0.706)**	**(0.672)**	**(9.178)**	**(10.59)**	**(0.519)**	**(0.552)**
1st stage est.								
Seaquake freq 1000km rad > 50km from the coast x Ln dist infra	-0.0024***		-0.0024***		-0.0020***		-0.0022***	
	(0.0008)		(0.0008)		(0.0007)		(0.0007)	
Seaquake freq 500km rad > 50km from the coast x Ln dist infra,		-0.0020***		-0.0020***		-0.0017***		-0.0018***
		(0.0008)		(0.0007)		(0.0006)		(0.0006)
Fixed effects	Country, year, country-year, sector, region, location.							
Controls	Yes							
Under-ident.. SW F-test	9.78***	8.82***	9.78***	8.82**	9.22***	8.38***	10.91***	10.21***
Weak indent. SW Chi-sq	13.52***	12.19***	13.52***	12.19***	12.68***	11.53***	15.00***	14.04***
N	219	219	219	219	229	229	229	229
# locations	109	109	109	109	114	114	114	114
# Countries	31	31	31	31	33	33	33	33

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors are presented in parentheses, are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

In a third step, to ensure that our results are not driven by firms operating in locations close to telecommunication infrastructures, we constrain our instrument set by considering only firms outside a 100km radius from infrastructure nodes, and by setting other firms' distance to infrastructure equal to 0. For the same concern, we also exclude from the analysis firms that are located in capital cities. Estimates resulting from the recalibrated instrument set are reported in table 6 while those resulting from the sample restriction are reported in table 7. Both tables support previously estimated effects on total sales and sales per worker, but the effect on FT employment does not hold anymore once excluding capital cities from the analysis.

Table 6. Digital vulnerability, email use, and firm performance, constrained instruments.

	(1)	(2)	(3)	(4)
Var dep:	**Total sales**	**Sales / worker**	**Direct exports[a]**	**# of FT employees**
Email use	**2.557****	**2.232*****	**-2.895**	**1.227*****
	(1.120)	**(0.762)**	**(10.19)**	**(0.452)**
1[st] stage est.				
Seaquake freq 100-500km x Ln dist infra	-0.0022***	-0.0022***	-0.0019**	-0.0021***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Seaquake freq 500-1000km x Ln dist infra	-0.0003	-0.0003	-0.0005	-0.0003
	(0.0017)	(0.0017)	(0.002)	(0.002)
Fixed effects	Country, year, country-year, sector, region, location.			
Controls	Yes			
Hansen test p-value	0.54	0.64	0.04	0.21
Under-ident.. SW F-test	7.55***	7.55***	5.73***	7.55***
Weak indent. SW Chi-sq	20.73***	20.73***	15.72***	20.73***
N	251	251	251	251
# locations	125	125	125	125
# Countries	38	38	38	38

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors in parentheses are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions. Constrained instrument use a distance variable that only considers firms located >100km from the closest infrastructure nodes, and takes a value of zero otherwise.

Table 7. Digital vulnerability, email use, and firm performance, excluding firms located in capital cities.

	(1)	(2)	(3)	(4)
Var dep:	**Total sales**	**Sales / worker**	**Direct exports[a]**	**# of FT employees**
Email use	**3.316*****	**3.062*****	**1.558**	**0.896**
	(0.703)	**(0. 6537)**	**(7.035)**	**(0.568)**
1[st] stage est.				
Seaquake freq 100-500km x Ln dist infra	-0.0025***	-0.0025***	-0.0024**	-0.0024***
	(0.0006)	(0.0006)	(0.0008)	(0.0006)
Seaquake freq 500-1000km x Ln dist infra	-0.0026	-0.0026	-0.0027	-0.0030
	(0.0022)	(0.0022)	(0.0023)	(0.0021)
Fixed effects	Country, year, country-year, sector, region, location.			
Controls	Yes			
Hansen test p-value	0.70	0.73	0.82	0.60
Under-ident.. SW F-test	10.92***	10.92***	11.60***	10.37***
Weak indent. SW Chi-sq	30.69***	30.69***	32.62***	28.96***
N	235	235	106	249
# locations	117	117	53	124
# Countries	38	38	18	41

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors in parentheses are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

In a fourth step, we make sur that our identification strategy is not affected by firms in our sample that have been surveyed at the province rather than the municipality-level. It is possible that firms located in province are sparsely distributed and more isolated, are more remote from infrastructures, and thereby, may drive previous estimates. We therefore proceed to data aggregation keeping in the sample only firms having been surveyed in municipalities, and run IV estimations of previous econometric models. Results are reported in table 8, and estimated coefficients are softer than previous estimates but relationships remain robust to this sample restriction.

Table 8. Digital vulnerability, email use, and firm performance, excluding firms located in province.

	(1)	(2)	(3)	(4)
Var dep:	**Total sales**	**Sales / worker**	**Direct exports[a]**	**# of FT employees**
Email use	**2.337***** **(0 .920)**	**1.704***** **(0. 6537)**	**0.008** **(4.729)**	**1.186***** **(0.201)**
1st stage est.				
Seaquake freq 100-500km x Ln dist infra	-0.0028** (0.0006)	-0.0028** (0.0006)	-0.0029** (0.0008)	-0.0028** (0.0006)
Seaquake freq 500-1000km x Ln dist infra	-0.0056*** (0.0020)	-0.0056*** (0.0020)	-0.0056*** (0.0023)	-0.0056*** (0.0020)
Fixed effects	Country, year, country-year, sector, region, location.			
Controls	Yes			
Hansen test p-value	0.70	0.61	0.69	0.60
Under-ident.. SW F-test	11.30***	11.30***	11.71***	11.30***
Weak indent. SW Chi-sq	34.52***	34.52***	35.77***	34.52***
N	179	179	106	179
# locations	89	89	53	89
# Countries	35	35	18	35

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors in parentheses are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

Fifth, landlocked countries are excluded because they cannot directly host SMCs, but can be indirectly connected to them via the terrestrial cable network. Although, country, country-year, and location fixed effects control for the consequences of this geographic feature on telecommunication outcomes, landlocked countries are particularly dependent on neighbouring coastal countries hosting SMCs, so that the non-treatment might act in a heterogeneous way in these countries. Results are reported in table 9 and stress a robust and stronger positive effect of email use on total sales and labour productivity in coastal economies. However, the effect of email use on employment is not robust to this restriction, as evidenced by the rejection of the Hansen test in column (4) and the weak and under-identification statistics in columns (5) and (6).

Table 9. Digital vulnerability, email use, and firm performance, excluding landlocked countries.

	(1)	(2)	(3)	(4)
Var dep:	Total sales	Sales / worker	Direct exports[a]	# of FT employees
Email use	**4.601***** **(0.997)**	**2.752***** **(0.717)**	**4.684** **(3.951)**	**1.253***** **(0.255)**
1st stage est.				
Seaquake freq 100-500km x Ln dist infra	-0.0022** (0.0009)	-0.0022** (0.0009)	-0.0025** (0.0008)	-0.0023** (0.0008)
Seaquake freq 500-1000km x Ln dist infra	-0.0061*** (0.0017)	-0.0061*** (0.0017)	-0.0070*** (0.0023)	-0.0066*** (0.002)
Fixed effects	Country, year, country-year, sector, region, location.			
Controls	Yes			
Hansen test p-value	0.42	0.52	0.70	0.07
Under-ident.. SW F-test	9.28***	9.28***	8.34***	10.26***
Weak indent. SW Chi-sq	30.76***	30.76***	28.53***	34.36***
N	114	114	106	112
# locations	57	57	53	56
# Countries	19	19	18	19

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors in parentheses are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

As last robustness check, we replace the instrumented variable of firm Internet use by a more general proxy of the telecommunication constraint experienced by the firm. This variable, drawn from the WBES, is an ordered categorical variable[10] reflecting the extent to which access to telecommunications represent an obstacle to the firm's operations. Results are reported in table 10 and strongly confirm baseline estimations.

Table 10. Digital vulnerability, telecommunication obstacle and firm performance.

	(1)	(2)	(3)	(4)
Var dep:	Total sales	Sales / worker	Direct exports[a]	# of FT employees
Telecom obstacle	**0.822***** **(0.125)**	**0.699***** **(0.189)**	**3.152** **(4.976)**	**0.281**** **(0.125)**
1st stage est.				
Seaquake freq 100-500km x Ln dist infra	-0.0078*** (0.002)	-0.0078*** (0.002)	-0.0025*** (0.0005)	-0.0085*** (0.002)
Seaquake freq 500-1000km x Ln dist infra	-0.0017 (0.009)	-0.0017 (0.009)	-0.0039*** (0.0015)	-0.00036 (0.009)
Fixed effects	Country, year, country-year, sector, region, location.			
Controls	Yes			
Hansen test p-value	0.26	0.54	0.56	0.82
Under-ident.. SW F-test	6.39***	6.39***	14.98***	10.77***
Weak indent. SW Chi-sq	17.58***	17.58***	41.13***	29.39***
N	243	243	251	259
# locations	121	121	125	129
# Countries	36	36	38	39

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors in parentheses are robust to heteroscedasticity and clustered by country. a: controls include the share of indirect exports, instead of the share of direct and indirect exports used in other regressions.

To sum up these results, table 11 reports estimated coefficients and standard errors obtained across estimations and robustness checks. Regarding the effect of email use on firms' sales, sales per worker, and employment, estimates all point to a more-than-proportional relationship. A 10% percentage point-increase in the penetration of Internet in locations leads to an increase in

[10] Becoming a continuous variable after aggregating it at the location level.

the average total sales ranging from 23% to 55%, in the average sales per worker ranging from 17% to 39%, in the average number of full-time employees ranging from 6% to 13%. The local spillovers of an increased Internet use on firms' revenue and productivity are therefore very important, in particular for domestic SMEs. The effect on employment being not robust to some robustness checks, we deepen this question in the next section.

Table 11. Overview of relationships estimated across regressions.

		(ln) Total sales	(ln) Sales per worker	(ln) # FT employees	% direct exports
(A) IV baseline estimations	**Coefficient**	**3.690*****	**2.607*****	**1.156*****	**3.152**
	Std error	0.906	0.573	0.389	4.977
(B) Excluding outliers.	**Coefficient**	**3.005*****	**2.201*****	**1.156*****	**5.093**
	Std error	0. 855	0.769	0.388	4.672
(C) Excluding large and foreign firms.	**Coefficient**	**5.454*****	**3.921*****	**0.608***	**-1.884**
	Std error	1.58	1.117	0.338	9.915
(D) Excluding seaquakes close to the coast.	**Coefficient**	**2.276*****	**2.014*****	**1.203****	**9.799**
	Std error	0.873	0.706	0.519	9.178
(E) Constrained instruments.	**Coefficient**	**2.557****	**2.232*****	**1.227*****	**-2.895**
	Std error	1.12	0.762	0.452	10.19
(F) Capital cities	**Coefficient**	**3.316*****	**3.062*****	**0.896**	**1.558**
	Std error	0.703	0. 6537	0.568	7.035
(G) Excluding landlocked countries.	**Coefficient**	**4.601*****	**2.752*****	**1.345*****	**4.684**
	Std error	0.997	0.717	0.271	3.951
(H) Municipalities	**Coefficient**	**2.337*****	**1.704*****	**1.186*****	**0.008**
	Std error	0 .920	0. 6537	0.201	4.729

Note: * significant at 10%, ** significant at 5%, *** significant at 1%.

4.3. Disentangling the effect of Internet use on employment

In this last subsection, given the high expectations placed in the digital economy's potential for job creation and inequality reduction in developing countries, and considering the weaker evidence on the effect of Internet use by firms on employment in some robustness checks, we proceed to a decomposition of this effect considering the type of position occupied by workers in surveyed firms. The literature on the ICT-employment nexus (Michaels et al, 2014; Akerman et al, 2015; Hjort & Poulsen, 2019) has stressed that technological change induced by the introduction of ICTs is biased in favour of an educated and skilled workforce. Weak evidence in earlier estimations could therefore be explained by this heterogeneous effect, explained by the existence of a "skill-biased technological change" (SBTC).

To disentangle this potentially ambiguous effect, we exploit information reported by manufactures on their workforce's type of occupation.[11] We therefore restrain the analysis on manufacture firms to further the analysis using disaggregated employment variables: the (logarithmic) number of non-production and production workers on the one hand, and the (logarithmic) number of skilled and unskilled production workers. Summary statistics on these dependent variables are provided in Appendix A.

[11] Such information for service firms was not available.

Estimations are conducted on the baseline sample (Table 12), but also on the four restricted samples (Table 13): domestic SMEs, coastal countries, excluding firms located in capital cities, and excluding firms located in provinces. Baseline estimations point to a positive and significant effect of Internet use on the number of both non-production and production workers (table 12, columns, (1) and (2)), but stronger on the latter. Estimates on columns (3) and (4) stress that the positive effect on production workers is driven by a large increase in unskilled production workers. Therefore, while Internet penetration is found to be beneficial to all types of employment in manufactures, i) the effect is heterogeneous between production and non-production workers, and ii) contrary to the SBTC hypothesis, unskilled production workers appear as the greater beneficiaries of an increased Internet use by manufacture firms.

Table 12. Digital vulnerability, email use, and firm employment.

	(1)	(2)	(3)	(4)
Var dep:	**Workers**		**Prod. Workers**	
	Non prod.	**Prod.**	**skilled**	**unskilled**
Email use	**2.197*** **	**3.510*** **	**0.085**	**4.123*** **
	(0.722)	**(1.045)**	**(0.691)**	**(1.448)**
1st stage est.				
Seaquake freq 100-500km x Ln dist infra	-0.0023***	-0.0023***	-0.0023***	-0.0023***
	(0.0005)	(0.0005)	(0.0006)	(0.0006)
Seaquake freq 500-1000km x Ln dist infra	-0.0026*	-0.0026*	-0.0027*	-0.0027*
	(0.0014)	(0.0014)	(0.0014)	(0.0014)
Fixed effects	Country, year, country-year, sector, region, location.			
Controls	Yes			
Hansen test p-value	0.46	0.46	0.25	0.25
Under-ident.. SW F-test	8.47***	8.47***	8.47***	8.47***
Weak indent. SW Chi-sq	23.13***	23.13***	23.13***	23.13***
N	255	255	255	255
# locations	127	127	127	127
# Countries	38	38	38	38
# aggregated firms	32,880			

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors in parentheses are robust to heteroscedasticity and clustered by country.

Estimations conducted on restricted samples of firms tend to confirm the stronger effect of Internet use on production workers compared to non-production workers (Table 13). An interesting finding is that increased Internet use by domestic SMEs is even found to reduce the number of skilled production worker positions while increasing the number of unskilled ones. This result points out that the relationship between ICT adoption and workforce skills is puzzling, especially in SMEs, so that the study of the effect of Internet on SMEs may need further explorations, as underlined by Giuri et al (2008). For the remaining restricted samples, including the sample resulting from the exclusion of firms located in capital cities, we find evidence consistent with estimates obtained from the baseline sample. With the exception that no difference in the response of skilled and unskilled production workers to Internet is found with the sample of coastal countries.

Table 13. Digital vulnerability, email use, and firm employment – Restricted samples.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Domestic SMEs				**Excluding landlocked countries**			
Var dep:	Workers		Prod. workers		Workers		Prod. workers	
	Non prod	Prod	skilled	unskilled	Non prod	Prod	skilled	unskilled
Email use	**0.565**	**0.670**	**-2.634*****	**3.130****	**2.736***	**4.981****	**2.439**	**5.018**
	(0.616)	**(1.020)**	**(1.093)**	**(1.489)**	**(1.644)**	**(2.494)**	**(2.183)**	**(3.172)**
1st stage est.								
Seaquake freq 100-500km x Ln dist infra	-0.0017***	-0.0017***	-0.0017**	-0.0017**	-0.0018***	-0.0018***	-0.0018***	-0.0018***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0008)	(0.0008)	(0.0008)	(0.0008)
Seaquake freq 500-1000km x Ln dist infra	-0.0037*	-0.0037*	-0.0037***	-0.0037***	-0.0029	-0.0029	-0.0029	-0.0029
	(0.0013)	(0.0013)	(0.0013)	(0.0013)	(0.0026)	(0.0026)	(0.0026)	(0.0026)
Fixed effects	Country, year, country-year, sector, region, location.				Country, year, country-year, sector, region, location.			
Controls	Yes				Yes			
Hansen test p-value	0.79	0.12	0.66	0.65	0.13	0.13	0.13	0.13
Under-ident.. SW F-test	5.52***	5.52***	5.52***	5.52***	2.75*	2.75*	2.75*	2.75*
Weak indent. SW Chi-sq	14.93***	14.93***	14.93***	14.93***	9.40***	9.40***	9.40***	9.40***
N	255	255	255	255	104	104	104	104
# locations	127	127	127	127	53	53	53	53
# Countries	38	38	38	38	17	17	17	17
	(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**
	Excluding firms located in capital cities				**Excluding firms located in provinces**			
Var dep:	Workers		Prod. workers		Workers		Prod. workers	
	Non prod	Prod	skilled	unskilled	Non prod	Prod	skilled	unskilled
Email use	**2.054****	**2.807****	**0.354**	**3.050***	**1.162**	**3.428****	**0.186**	**6.514*****
	(0.978)	**(0.903)**	**(1.847)**	**(1.670)**	**(1.644)**	**(1.634)**	**(1.847)**	**(2.163)**
1st stage est.								
Seaquake freq 100-500km x Ln dist infra	-0.0023***	-0.0023***	-0.0023***	-0.0023***	-0.0014**	-0.0014**	-0.0014**	-0.0014**
	(0.0007)	(0.0007)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Seaquake freq 500-1000km x Ln dist infra	-0.0032	-0.0032	-0.0032	-0.0032	-0.0012	-0.0012	-0.0012	-0.0012
	(0.0026)	(0.0026)	(0.0026)	(0.0026)	(0.0026)	(0.0026)	(0.0026)	(0.0026)
Fixed effects	Country, year, country-year, sector, region, location.				Country, year, country-year, sector, region, location.			
Controls	Yes				Yes			
Hansen test p-value	0.45	0.45	0.22	0.55	0.58	0.58	0.48	0.48
Under-ident.. SW F-test	10.00***	10.00**	10.00**	10.00**	6.75**	6.75**	6.75**	6.75**
Weak indent. SW Chi-sq	28.21***	28.21***	28.21***	28.21***	20.73***	20.73***	20.73***	20.73***
N	233	233	233	233	177	177	177	177
# locations	116	116	116	116	88	88	88	88
# Countries	38	38	38	38	35	35	35	35

Note: * significant at 10%, ** significant at 5%, *** significant at 1%. Control estimates not reported. Standard errors in parentheses are robust to heteroscedasticity and clustered by country.

5- Discussion and concluding remarks

This paper provides evidence of a large and positive impact of ICT diffusion on firms' performance at the location level. Using email is found to be a consistent way for firms to boost sales, productivity, and employment. According to baseline FE-IV estimations, a 10% increase in the use of email in the population of firms raises by 36% the firms' average annual sales, by 26% average sales per worker, by 12% the average number of full-time permanent workers. These findings are found to be mainly driven by the sector of services, and to resist to various robustness tests. They therefore highlight the existence of large spillovers or network externalities of Internet diffusion at the location level.

Then, we furthered the analysis of the effect of Internet diffusion among manufactures on their employment outcomes, by looking at the effect on production and non-production workers, and on skilled and unskilled production workers. Results highlight a positive and significant effect of Internet penetration on both production and non-production workers, but a stronger effect on the former. They also stress that the previous positive effect of Internet on production workers is driven by increase in the number of unskilled production workers. Therefore, the potential of Internet diffusion for employment and inequality reduction in developing and transition countries seems confirmed by these results.

Through the IV approach followed in this paper, we also pointed out the rise of new digital vulnerabilities countries may be subject to: the arrival of SMCs has boosted the Internet economy as a whole but has also increased the economy's exposure to fibre cable breaks and Internet shutdowns. First, our results specifically stress the importance of the SMC network exposure to seismic risk for the development of the Internet economy and for the performance of firms, but the underlying mechanisms can be extended to other previously sources of cable faults, such as maritime activities, piracy, or other natural hazards. Second, we show that the location distance to IXPs or SMC landing stations is a critical transmission factor of the effect of seismic shocks on Internet diffusion among firms. Therefore, firms that are remote from infrastructures face geographical handicaps that increase their exposure to telecommunication disruptions, which may deprive them of the potential benefits of the digital revolution.

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Appendix A. Summary statistics

A.1. Summary statistics (location-level)

	Obs.		mean		std. dev		min		max	
	Firm	Location	Firm	Location	Firm	Location	Firm	Location	Firm	Location
Dependent variables										
Ln Total sales (USD)	26,965	250	13.30	12.96	2.82	1.95	0	8.86	27.37	20.43
Ln Sales per worker (USD)	26,852	250	10.19	9.93	2.40	1.81	0	6.09	24.92	17.80
Ln # fulltime employees	31,925	250	3.25	3.16	1.27	0.44	0	2.03	9.93	4.18
Ln # non-production workers	14,904	244	2.07	1.99	1.28	0.525	0	0.379	8.82	3.13
Ln # production workers	14,947	244	3.00	3.00	1.30	0.477	0	1.73	9.58	3.98
Ln # skilled production workers	14,732	244	2.46	2.52	1.34	0.54	0	0.60	9.47	3.79
Ln # unskilled production workers	14,551	244	1.59	1.51	1.53	0.56	0	0.00	8.01	3.00
Variable of interest										
Dummy email use	32,098	250	0.70	0.63	0.46	0.27	0	0.05	1.00	1.00
Telecommunication obstacle	22,824	250	1.10	1.10	1.32	0.65	0	0	4.00	3.09
Control variables										
Ln Firm age	32,169	250	2.67	2.62	0.79	0.31	0	1.65	4.74	3.33
Dummy state-owned	32,178	250	0.03	0.03	0.17	0.12	0	0.00	1.00	1.00
Dummy foreign-owned	32,178	250	0.09	0.08	0.29	0.09	0	0.00	1.00	0.64
Ln # initial FT employees	29,177	250	2.34	2.37	1.19	0.37	0	1.58	13.82	3.38
% of exports (direct + indirect)	31,848	250	7.69	7.21	21.31	5.79	0	0.00	100.00	39.02
Ln # power outages	17,242	250	1.50	1.47	1.11	0.87	0	0.00	6.31	4.41
Instruments= (A) x (B)										
Seaquake annual freq., [100; 1000] km rad. (A)	32,178	250	6.44	4.28	13.36	11.01	0	0	44	44
Ln firm distance (km) to infrastructures (B)	32,178	250	3.60	4.58	2.65	2.26	0	0	7.82	7.81

A.3. Baseline firm-level sample composition

38 countries, 32,178 firms

iso	2006	2007	2008	2009	2010	2011	2013	2014	Total
AFG	0	0	436	0	0	0	0	410	846
AGO	425	0	0	0	360	0	0	0	785
ARG	1,063	0	0	0	982	0	0	0	2,045
ARM	0	0	0	354	0	0	343	0	697
AZE	0	0	0	380	0	0	390	0	770
BIH	0	0	0	361	0	0	311	0	672
BLR	0	0	273	0	0	0	360	0	633
BOL	613	0	0	0	362	0	0	0	975
BWA	342	0	0	0	268	0	0	0	610
COL	1,000	0	0	0	942	0	0	0	1,942
GEO	0	0	210	0	0	0	204	0	414
GHA	0	345	0	0	0	0	419	0	764
GTM	522	0	0	0	590	0	0	0	1,112
HND	436	0	0	0	360	0	0	0	796
KAZ	0	0	0	544	0	0	600	0	1,144
KGZ	0	0	0	133	0	0	146	0	279
MDA	0	0	0	363	0	0	360	0	723
MDG	0	0	0	14	0	0	30	0	44
MKD	0	0	0	366	0	0	360	0	726
MLI	0	490	0	0	360	0	0	0	850
MNG	0	0	0	362	0	0	360	0	722
NIC	478	0	0	0	336	0	0	0	814
NPL	0	0	0	368	0	0	482	0	850
PAN	540	0	0	0	258	0	0	0	798
PRY	613	0	0	0	361	0	0	0	974
ROM	0	0	0	348	0	0	354	0	702
RWA	212	0	0	0	0	241	0	0	453
SLV	401	0	0	0	223	0	0	0	624
SRB	0	0	0	242	0	0	209	0	451
TJK	0	0	261	0	0	0	239	0	500
TZA	355	0	0	0	0	0	601	0	956
UGA	563	0	0	0	0	0	688	0	1,251
UKR	0	0	851	0	0	0	1,002	0	1,853
URY	621	0	0	0	607	0	0	0	1,228
VEN	500	0	0	0	320	0	0	0	820
YEM	0	0	0	0	301	0	151	0	452
ZAR	340	0	0	0	359	0	0	0	699
ZMB	0	484	0	0	0	0	720	0	1,204
Total	**9,024**	**1,319**	**2,031**	**3,835**	**6,989**	**241**	**8,329**	**410**	**32,178**

A.4. Baseline location-level sample composition

38 countries, 125 locations, 250 observations

iso	2006	2007	2008	2009	2010	2011	2013	2014	Total
AFG	0	0	5	0	0	0	0	5	10
AGO	3	0	0	0	3	0	0	0	6
ARG	4	0	0	0	4	0	0	0	8
ARM	0	0	0	3	0	0	3	0	6
AZE	0	0	0	4	0	0	4	0	8
BIH	0	0	0	4	0	0	4	0	8
BLR	0	0	6	0	0	0	6	0	12
BOL	3	0	0	0	3	0	0	0	6
BWA	2	0	0	0	2	0	0	0	4
COL	4	0	0	0	4	0	0	0	8
GEO	0	0	3	0	0	0	3	0	6
GHA	0	2	0	0	0	0	2	0	4
GTM	2	0	0	0	2	0	0	0	4
HND	3	0	0	0	3	0	0	0	6
KAZ	0	0	0	5	0	0	5	0	10
KGZ	0	0	0	2	0	0	2	0	4
MDA	0	0	0	4	0	0	4	0	8
MDG	0	0	0	1	0	0	1	0	2
MKD	0	0	0	4	0	0	4	0	8
MLI	0	4	0	0	4	0	0	0	8
MNG	0	0	0	5	0	0	5	0	10
NIC	2	0	0	0	2	0	0	0	4
NPL	0	0	0	3	0	0	3	0	6
PAN	1	0	0	0	1	0	0	0	2
PRY	2	0	0	0	2	0	0	0	4
ROM	0	0	0	6	0	0	6	0	12
RWA	2	0	0	0	0	2	0	0	4
SLV	1	0	0	0	1	0	0	0	2
SRB	0	0	0	2	0	0	2	0	4
TJK	0	0	3	0	0	0	3	0	6
TZA	3	0	0	0	0	0	3	0	6
UGA	5	0	0	0	0	0	5	0	10
UKR	0	0	5	0	0	0	5	0	10
URY	2	0	0	0	2	0	0	0	4
VEN	3	0	0	0	3	0	0	0	6
YEM	0	0	0	0	4	0	4	0	8
ZAR	4	0	0	0	4	0	0	0	8
ZMB	0	4	0	0	0	0	4	0	8
Total	**46**	**10**	**22**	**43**	**44**	**2**	**78**	**5**	**250**

A.5. Baseline sample composition, by region

	Firm-level data		Location-level data	
Region	**Obs.**	**Percent**	**Obs.**	**Percent**
AFR	7,616	23.67	60	24
EAP	360	1.12	5	2
ECA	9,926	30.85	107	42.8
LAC	12,128	37.69	54	21.6
MNA	452	1.4	8	3.2
SAR	1,696	5.27	16	6.4
Total	**32,178**	**100**	**250**	**100**

A.6. Baseline sample composition, by sector

Sector	Freq.	% firms	% locations
Manufactures	16,244	50.48	44.4
Services	15,934	49.52	55.6
Textiles	1,138	3.54	3.01
Leather	303	0.94	1.57
Garments	2,428	7.55	6.21
Food	4,014	12.47	12.46
Metals and machinery	1,912	5.94	5.47
Electronics	193	0.6	0.63
Chemicals and pharmaceuticals	1,262	3.92	2.45
Wood and furniture	407	1.26	1.26
Non-metallic and plastic materials	1,276	3.97	3.87
Auto and auto components	24	0.07	0.08
Other manufacturing	3,396	10.55	8.63
Retail and wholesale trade	8,938	27.78	30.69
Hotels and restaurants	1,506	4.68	5.67
Other services	3,260	10.13	10.17
Other: Construction, Transportation, etc	2,094	6.51	7.79
Other	27	0.08	0.05
Total	**32,178**	**100**	**100**

Appendix B. Instrument set: data collection and treatment

B.1. Infrastructure deployment variables

Raw data on SMCs are drawn from Telegeography:

- All cables with date of commissioning
- All the landing stations of cables and their GPS coordinates

Raw data on Internet Exchange Points are drawn from Telegeography and completed by the *Packet Clearing House* and *Peering DB* databases:

- All IXPs with their status (active/inactive/project)
- their year of activation
- their GPS coordinates

After a conversion into polygons (disk with 5 km diameter) to avoid topological inaccuracies, the SMC landing stations and IXPs from each country are identified and located, and counted.

B.2. firm distance to infrastructure nodes

A distance raster map is defined from all coordinate points, which gives the distance of each firm to the nearest Internet Exchange Point.

Statistical inputs: SMC landing station coordinates, IXPs' coordinates, firm's city location coordinates.

Firms' location centroids (WBES), SMC landing station coordinates (Telegeography), and IXPs coordinates (Telegeography, peering DB) give points for which the distances to SMCs are calculated using the previously calculated distance raster. In some countries, firms may have been pooled and interviewed by province rather than municipality of location. In this case, we take the province's centroid as firm's location coordinates. The firm distance to infrastructure variable is the minimum distance for the firm to reach the closest infrastructure node: either a landing station or an IXP.

B.3. Exposure to seaquake-induced cable faults

The Northern California Earthquake Data Center of the University of Berkeley provides a global database of earthquakes. For each country, we get for each year the number, the location, and the average magnitude of epicenters of occurring seaquakes, and are therefore able to compute the annual frequency of seaquakes near the stations according a 1000 km radius.

To ensure that we do not take into account seaquakes that could induce tsunamis, which would hence violate restriction identification conditions, we drop observations when seaquake magnitude exceeds 6.5 on the Richter scale. To ensure that we do take into account seaquakes that are strong enough to induce cable faults, we only count seaquakes which magnitudes exceeds 5 on the Richter scale. All in all, seaquakes considered for the empirical analysis are those occurring within a 1000 km radius from SMC landing station.

"Sur quoi la fondera-t-il l'économie du monde qu'il veut gouverner? Sera-ce sur le caprice de chaque particulier? Quelle confusion! Sera-ce sur la justice? Il l'ignore."

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