FONDATION POUR LES ÉTUDES ET RECHERCHES SUR LE DÉVELOPPEMENT INTERNATIONAL

Submarine cable vulnerability and local performance of firms in developing and transition countries

Credit: Microsoft

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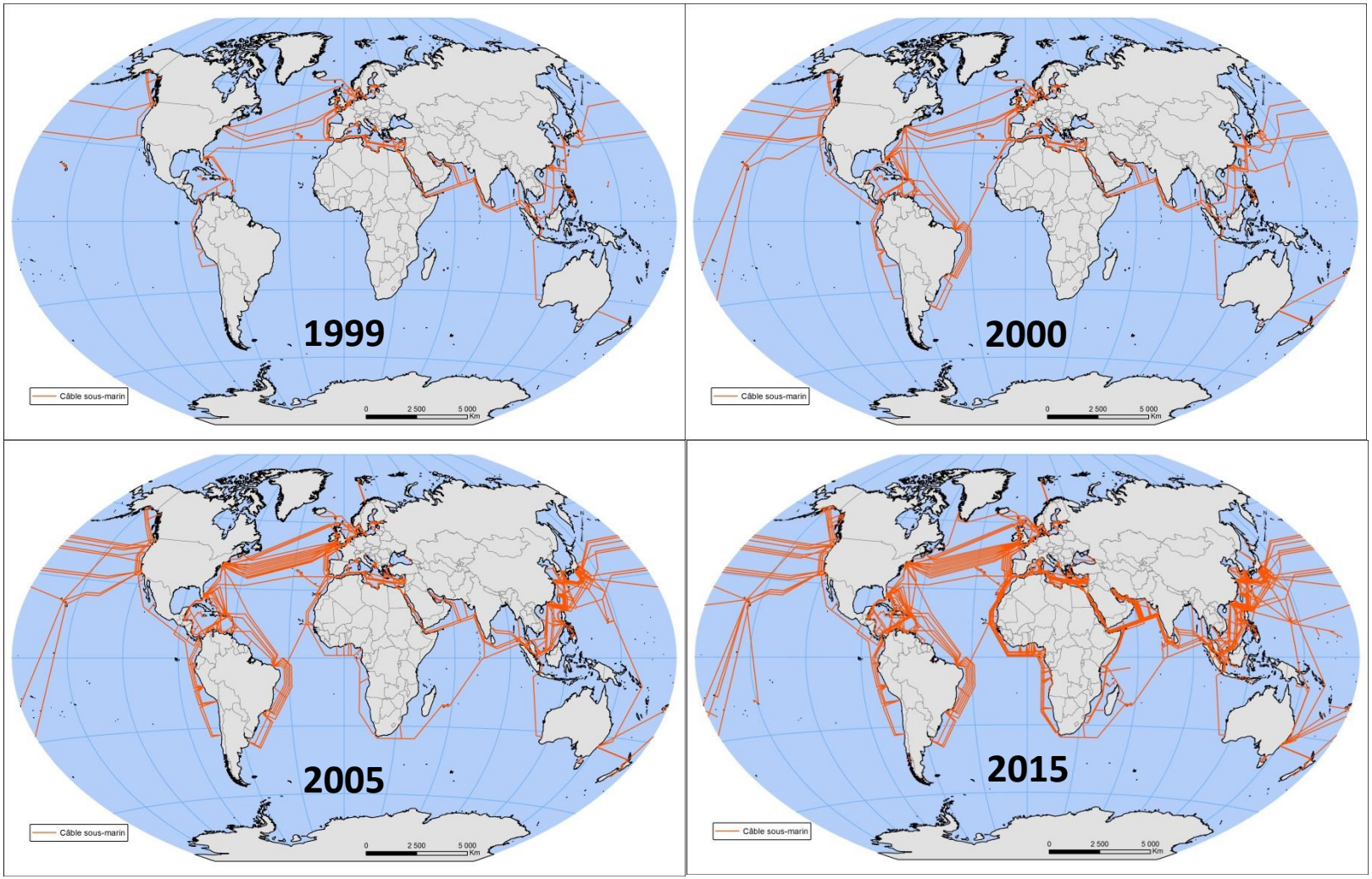
For the last decades, international connectivity of developing countries underwent a dramatic improvement, by the laying of hundreds of **fiber-optic telecommunications submarine cables (SMCs):**

- Bringing fast and affordable Internet to developing countries (Aker & Mbiti, 2010)
- Irrigating a USD 20.4 trillion industry, and
- Connecting 3 billion Internet users worldwide (Internet Society 2015).

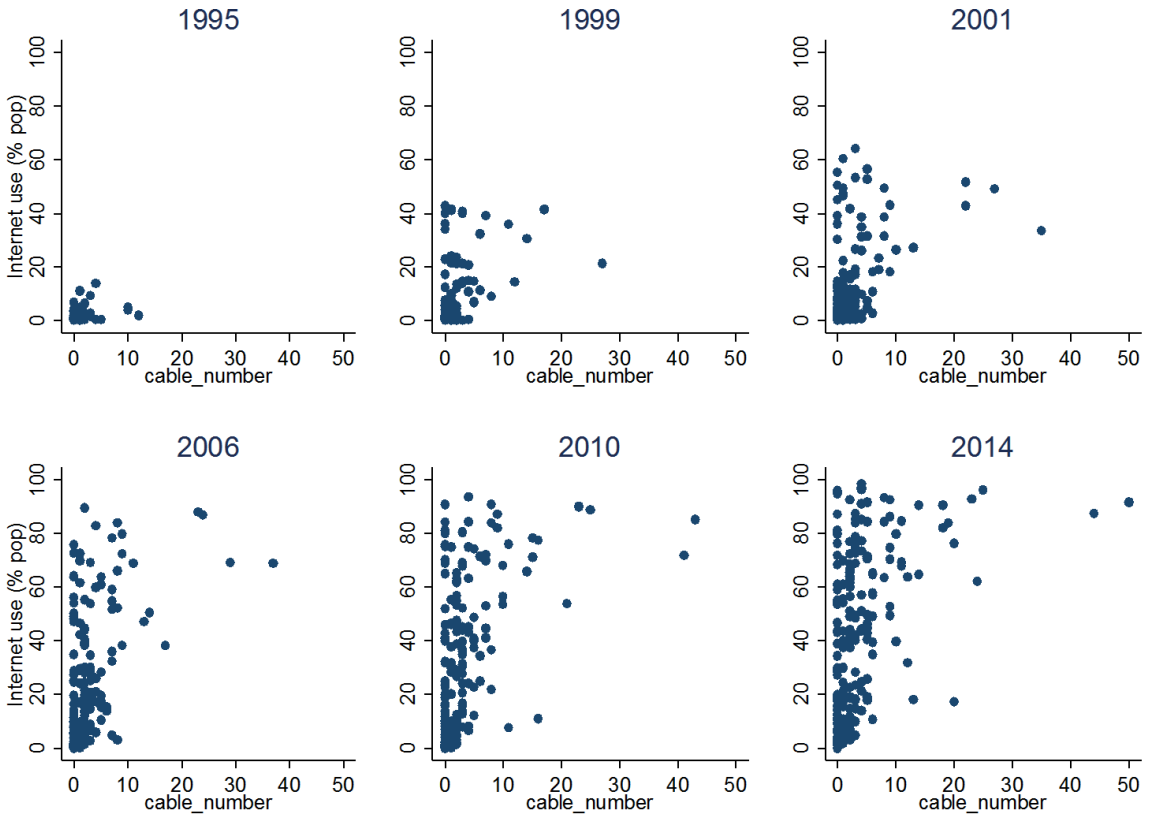
In 2013, "20 households with average broadband usage generate as much traffic as the entire Internet carried in 1995" (OECD, 2013)

In 2016, more than 99% of the world telecommunications passes through SMCs.

The submarine telecom infrastructures are now one of the mainstays of the global economy

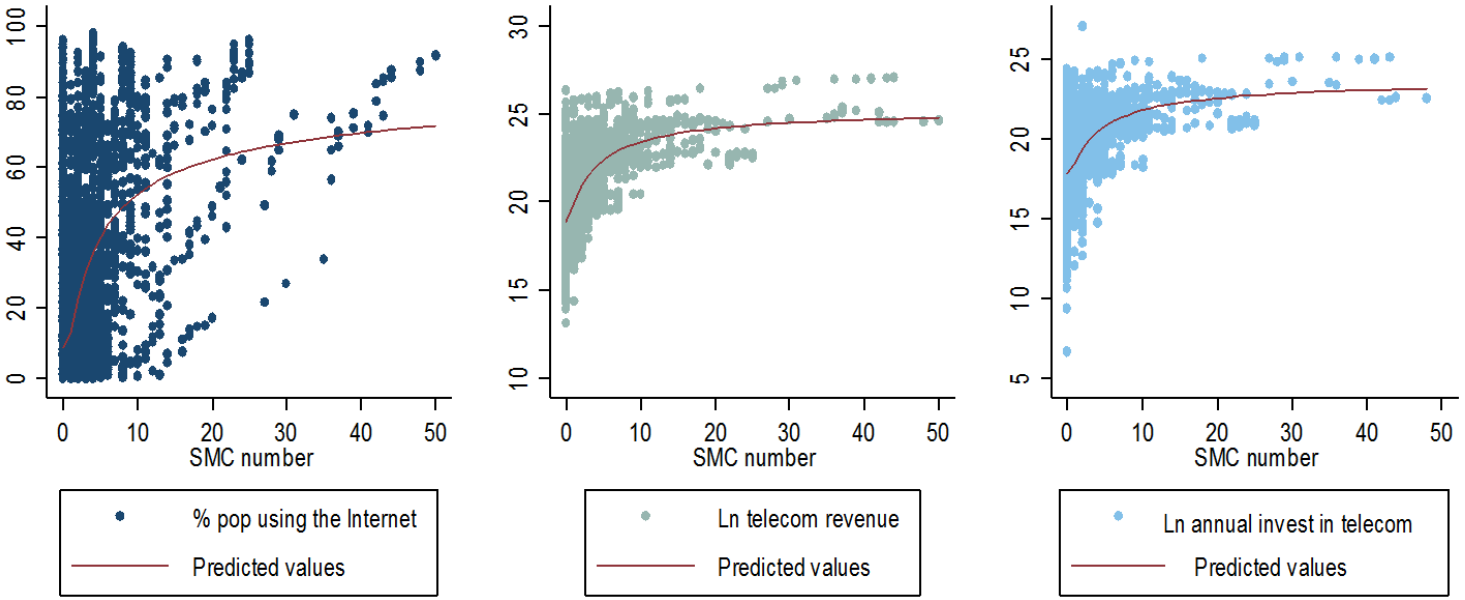

1999
2000
2005
2015
Câble sous-marin
0
2 500
5 000
Km

SMC deployment and Internet penetration worldwide



Notes: Raw data from ITU (2016) and Telegeography (2016).

SMC deployment and telecommunication outcomes



Notes: world evidence, 1990-2014**.** Raw data from ITU (2016) and Telegeography (2016).

What are the expected dividends from the deployment of these cables, *a fortiori* from ICTs diffusion in developing countries?

ICTs are a **general purpose technology,** with a positive effect on:

- **Domestic activity:** Economic growth (Roller & Waverman, 2001; Choi & Yi, 2009; Andrianaivo & Kpodar, 2011), employment (Hjort & Poulsen, 2019) and labor productivity (Clarke et al., 2015; Paunov & Rollo, 2015; Cette et al, 2016)
- **Foreign exchanges:** trade (Freund & Weinhold, 2004; Clarke & Wallsten, 2006), attractiveness (Choi, 2003), and exports (Clarke, 2008; Hjort & Poulsen, 2019)
- **Agricultural development** (Jansen, 2007; Eygir et al. , 2011; Aker & Fafchamps, 2013)
- **Institutional quality:** Governance (Andersen et al., 2011; Asongu and Nwachukwu, 2016), political stability (Stodden et Meier, 2009)

Among other development outcomes (health, education, innovation, etc.)…

This paper brings additional insights into this line of research by:

- Providing evidence on the location-level impact of Internet use by firms on their **revenue, labour productivity, and employment**.
- Conducting the analysis at the location level to account for network externalities and within-country heterogeneity in Internet penetration among firms
- Adopting a instrumental variable approach, emphasizing a new vulnerability arising from SMC deployment: **the SMC network's exposure to seismic risk**.

This paper indirectly tries to provide an answer to the following question:

What happens to firms when the SMC network integrity is threatened ?

The model

Using data aggregated at the location-level, we estimate the following general model:

$$Y_{j,l,t} = \gamma_0 + \gamma_1 Internet_{j,l,t} + \gamma_2 X_{j,l,t} + \partial_j + \mu_r + \sigma_l + \delta_t + \beta_{j,t} + \varepsilon_{j,l,t} \quad (1)$$

- subscripts, *l, t, j, r* respectively refer to the location, the survey year, the country, and the region.
- $Y_{j,l,t}$, and $Internet_{j,l,t}$ are respectively variables of firm's performance, and firm's Internet use. $\varepsilon_{j,l,t}$ is the error term.
- $X_{j,l,t}$: average number of full time permanent employees when the firm has started operations, the firm's age, the ownership structure (state and foreign ownership, in %), the % of direct and indirect exports, the frequency of power outages, and the sector of activity.
- We also control for country (∂_j), year (δ_t), country x year ($\beta_{j,t}$), region (μ_r), and for location (σ_l) fixed effects.

The data

Sample of more than 30,000 firms, located in around 125 cities/provinces in some 38 developing and transition countries.

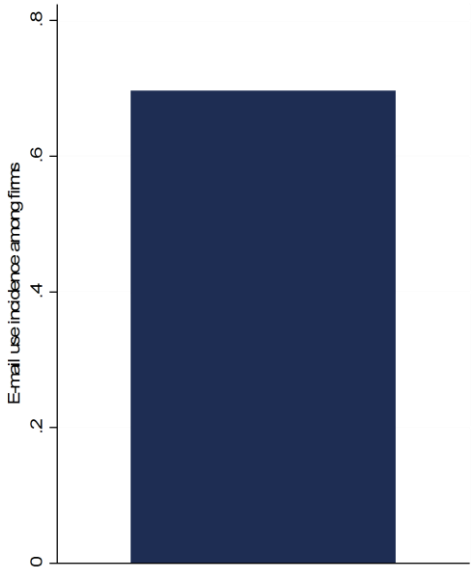
All firm-level variables used in our model are drawn from the World Bank Enterprise Survey (WBES) harmonized cross-sectional dataset.

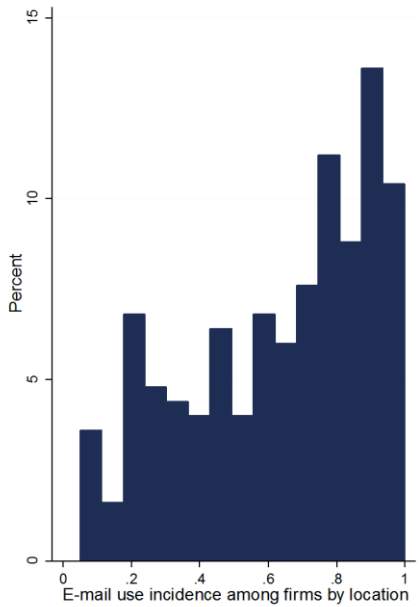
A **pseudo panel** is built by aggregating at the location level firm-level data from the World Bank Enterprise Surveys (city or province), and keeping locations where firms have been at least twice surveyed:

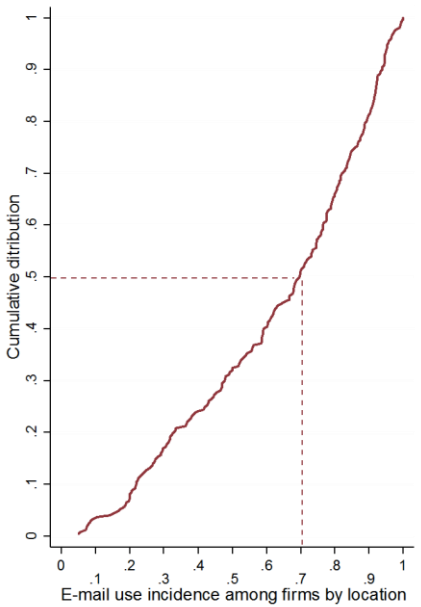
- **To account for local externalities** between firms' decisions located in the same place, that could bias estimates;
- and **to control for local unobserved heterogeneity**, by applying the within FE estimator.

Interest variable ($Internet_{l,t}$)

- % of firms which declares having used emails to communicate with its clients and suppliers during the past year
- most basic way to use Internet, reflecting both simple and more complex usages of the Internet



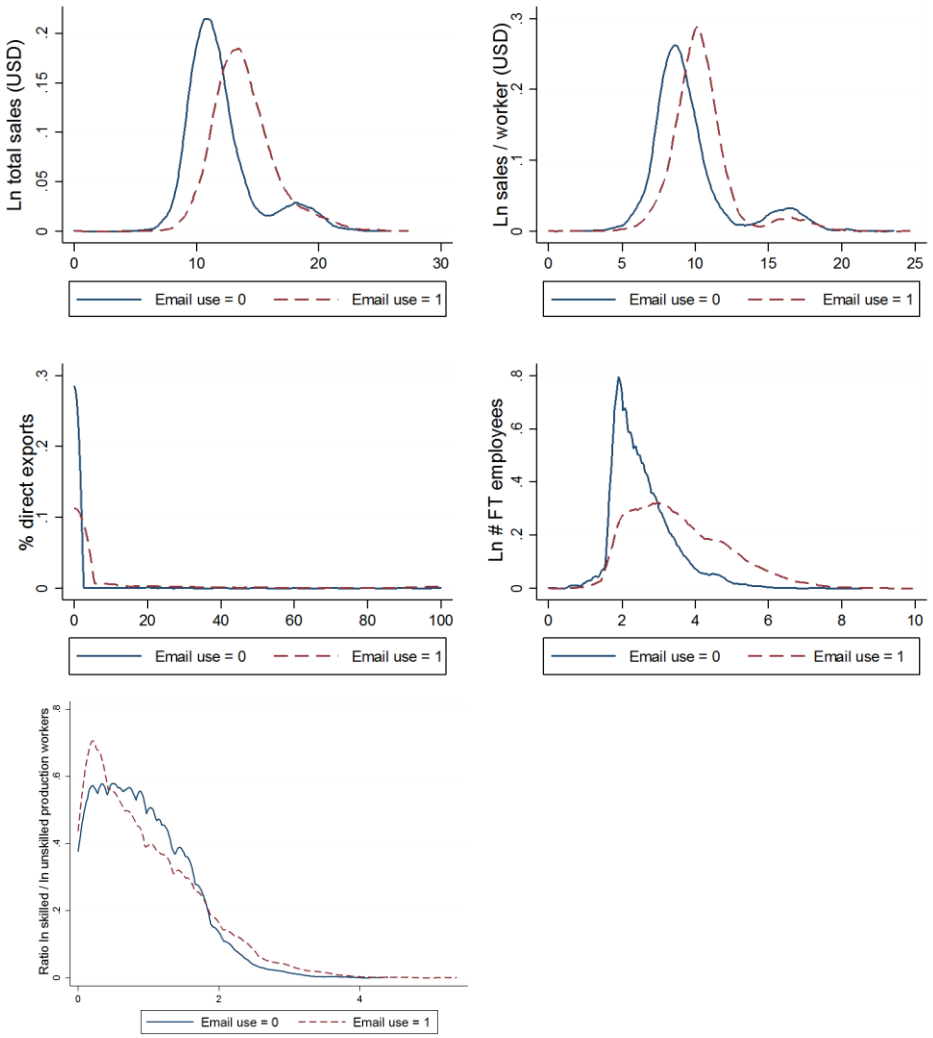




6 outcome variables (Y_{lt}):

- ❑Log total annual sales (in USD).
- ❑Log sales / FT permanent employees
- ❑% of direct exports
- ❑Log # of FT permanent employees
- ❑Log # of skilled production workers
- ❑Log # of unskilled production workers

Firm outcomes & Internet use.



IV framework

- FE 2-stage least square estimator (FE-2SLS), adding the 1st-stage equation to eq. (1):

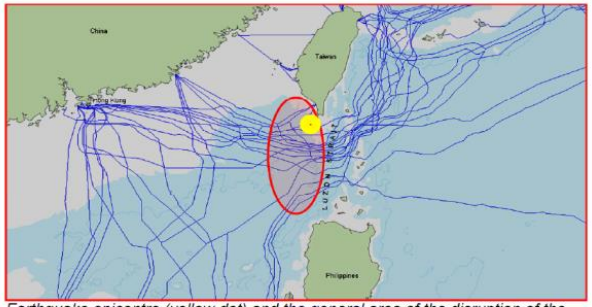
$$Internet_{l,t} = \alpha_0 + \delta_1 Instruments_{j,l,t} + \alpha_2 X_{j,l,t} + \partial_j + \pi_s + \mu_r + \sigma_l + \delta_t + \beta_{j,t} + \varepsilon_{j,l,t} \quad (2)$$

Instrument$_{j,l,t}$ = SMC network exposure to shocks$_{j,t}$ (A) x Location exposure to telecom disruptions$_{j,l}$ (B)

- Our instrument combine two structural interrelated sources of digital vulnerability :
  - (A): the **SMC network exposure to seismic shocks**
  - (B): **digital isolation**, i.e. the location distance from key infrastructures, increasing the exposure to telecommunication disruptions.
- Location fixed-effects: control for location's time-invariant characteristics explaining firm's location choice and outcomes
- Region, country, year, country-year fixed effects: control, among others, for the endogenous timing of SMC laying in a given country.

SMC exposure to seismic risk

- Seaquakes erode or break entire sections of the cable network SMCs (multiple cables, multiple breaks)
- Destabilize the seabed into which cables are buried
- Affect the likelihood of future faults caused by other shocks

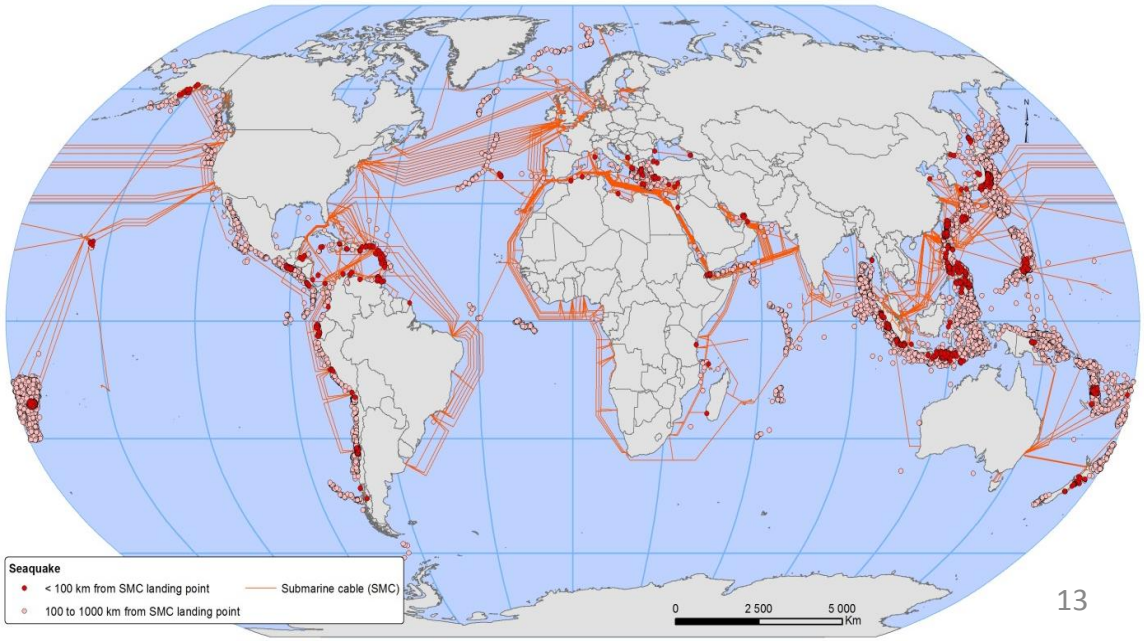


Earthquake epicentre (yellow dot) and the general area of the disruption of the submarine cables (blue lines). Courtesy Global Marine Systems Ltd

Taiwan earthquake (7 on RS)in 2006. 8 SMC cuts.

Disrupted East-Asian & international telecommunications

International seismic activity within a 100 or 1000km radius from SMC landing stations, 2005-2017.



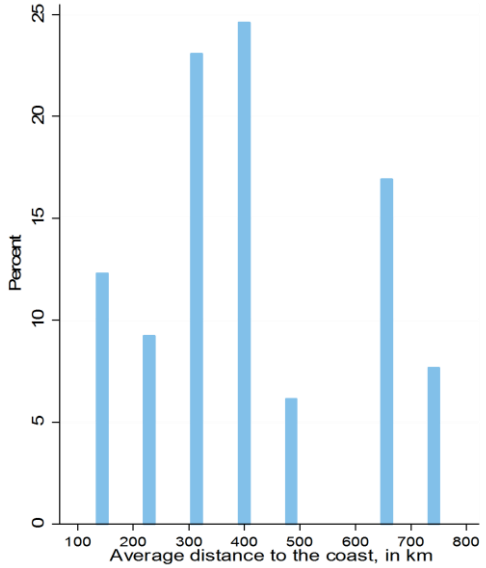
SMC exposure to seismic risk

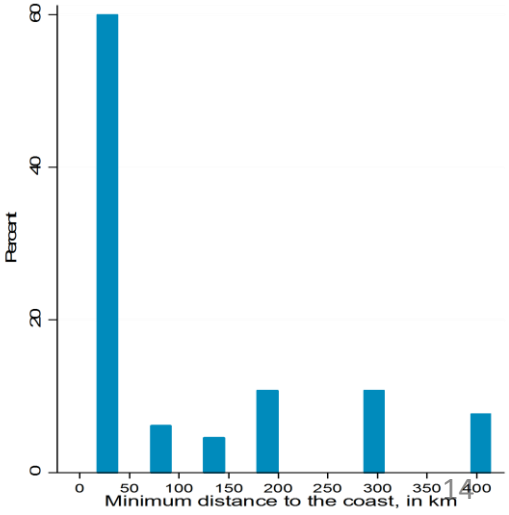
Seismic shock variable = the **annual frequency of medium size seaquakes** that are likely to affect only the functioning of SMCs,

- ❑ i.e. located within a **100-1000km radius from SMC landing stations**
- ❑ Low-magnitude seaquakes (<5 on Richter scale) **are not counted**
- ❑ Obs. with high-magnitude seaquakes (>6.5 on Richter scale) **are dropped**

Robustness:

- ❑ Drop observations when the minimum distance of seaquakes to the coast < 50km (60% instrument obs.).





Digital isolation

When telecommunication assets are geographically concentrated (mostly the case in developing countries), locations distant from telecommunication nodes, are :

- More exposed to telecommunication disruptions (Grubesic and Murray, 2006; Grubesic et al, 2003),
- and are slower to recover after telecommunication shutdowns (Gorman and Malecki, 2000; Gorman et al., 2004).

Digital isolation variable parametrisation:

- We compute the (ln) distance in km between locations' centroid and the closest key infrastructure nodes GPS coordinates.
- Infrastructures nodes are **SMC landing stations** or **Internet Exchange Points**, which are key infrastructures for the telecom network's capacity and efficiency.

Robustness:

- distance set to 0 for locations within 100km rad from infrastructure nodes
- Excluding from the sample firms located in capital cities
- Excluding from the sample firms located in provinces

Instrument set

The instrument set combines:

- **Instrument$_{l,t}$ 1:** Seaquake freq, 100-500km radius x Ln location distance to infrastructures
- **Instrument$_{l,t}$ 2**: Seaquake freq, 500-1000km radius x Ln location distance to infrastructures

Take into account non linear effect depending on seaquake distance to SMC, and to compute identification stat.

Baseline estimations

	(ln) Total sales	(ln) Sales per worker	(ln) # FT employees	(ln) skilled workers	(ln) unskilled workers	% direct exports
Email use	**3.690*** (0.906)**	**2.607*** (0.573)**	**1.156*** (0.389)**	**0.085 (0.691)**	**4.123*** (1.448)**	**3.152 (4.977)**
State-owned	2.236 (1.582)	2.011* (1.146)	-0.413 (0.715)	0.996 (1.272)	-4.762** (1.896)	-6.784 (8.734)
Foreign	-3.192** (1.591)	-2.685** (1.048)	0.302 (0.535)	2.153** (0.853)	-4.498*** (1.366)	23.22** (9.983)
Age	0.374 (0.245)	-0.0951 (0.209)	0.579*** (0.197)	0.575 (0.401)	0.991 (1.050)	-6.593*** (1.798)
# power outages	-0.456*** (0.150)	-0.289*** (0.111)	-0.0184 (0.039)	-0.302 (0.115)	-0.159 (0.271)	0.0230 (0.903)
% of exports	0.0298*** (0.00823)	0.0153 (0.0105)	0.007* (0.003)	-0.016 (0.012)	-0.029 (0.018)	-0.157 (0.184)
Initial # of FT employee	0.358*** (0.138)	0.221 (0.141)	0.0155 (0.0780)	0.061 (0.151)	-0.343 (0.229)	0.435 (1.530)
First stage estimates						
Seaquake freq 100-500km x Ln dist infra	-0.0026*** (0.0005)	-0.0026*** (0.0005)	-0.0025*** (0.0005)	-0.0023*** (0.0006)	-0.0023*** (0.0006)	-0.0025*** (0.0005)
Seaquake freq 500-1000km x Ln dist infra	-0.0039*** (0.0014)	-0.0039*** (0.0014)	-0.0039*** (0.0014)	-0.0027* (0.0014)	-0.0027* (0.0014)	-0.0039*** (0.0014)
Controls			Yes			Yes[a]
Fixed effects			country, year, country-year, sector, region, location			
Hansen test (p. value)	0.27	0.72	0.33	0.25	0.25	0.56
Weak-identification SW F-test	17.81***	17.81***	17.81***	8.47***	8.47***	14.98***
Underidentification SW Chi-sq.	48.92***	48.92***	48.92***	23.13***	23.13***	41.13***
N	251	251	251	255	255	251
# locations	125	125	125	127	127	125
# countries	38	38	38	38	38	38
# aggregated firms	32,178	32,178	32,178	32,880	32,880	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.

Manufacture vs Service

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Sales		Sales/worker		Direct exports		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)**
State-owned	2.250**	2.789	1.051	1.018	-9.401*	14.10*	1.189***	0.333
	(1.136)	(1.986)	(0.694)	(1.444)	(4.956)	(8.000)	(0.406)	(0.648)
Foreign	-0.661	-0.276	-2.059**	0.805	5.122	12.91*	1.115***	0.478
	(1.249)	(1.373)	(0.975)	(0.684)	(5.597)	(7.817)	(0.414)	(0.716)
Age	0.875*	0.869	0.708**	-0.235	-1.420	-3.441*	0.143	0.672*
	(0.499)	(0.543)	(0.313)	(0.278)	(1.832)	(1.832)	(0.216)	(0.358)
# power outages	0.262	-0.00535	0.0233	-0.0912	-0.240	0.0267	0.106	0.0564
	(0.203)	(0.164)	(0.121)	(0.112)	(0.727)	(0.907)	(0.0731)	(0.0852)
% of exports	0.0242*	-0.0111	0.0072	-0.0173	0.646***	0.487***	0.0056	0.0038
	(0.0127)	(0.0185)	(0.0081)	(0.0152)	(0.089)	(0.102)	(0.0058)	(0.0057)
Initial # of FT employee	0.796***	-0.472**	0.198	-0.0587	-3.466**	3.669*	0.295**	-0.149
	(0.275)	(0.186)	(0.160)	(0.155)	(1.506)	(1.898)	(0.125)	(0.0910)
First stage estimates:								
Seaquake freq 100-500km	-0.0025***	-0.0015***	-0.0025***	-0.0015***	-0.0025***	-0.0015***	-0.0015***	-0.0015***
x Ln dist infra	(0.0005)	(0.0004)	(0.0005)	(0.0004)	(0.0005)	(0.0004)	(0.0004)	(0.0004)
Seaquake freq 500-1000km	-0.0026	-0.0061***	-0.0026	-0.0061***	-0.0026	-0.0061***	-0.0061***	-0.0061***
x Ln dist infra	(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 are clustered by country

Summary

		(ln) Total sales	(ln) Sales per worker	(ln) # FT employees	% direct exports	(ln) skilled workers	(ln) unskilled workers
(A) IV baseline estimations	**Coefficient**	**3.690*****	**2.607*****	**1.156*****	**3.152**	**0.085**	**4.123*****
	Std error	0.906	0.573	0.389	4.977	-0.691	1.448
(B) Excluding outliers.	**Coefficient**	**3.005*****	**2.201*****	**1.156*****	**5.093**	**0.085**	**3.066*****
	Std error	0. 855	0.769	0.388	4.672	0.691	1.029
(C) Excluding large and foreign firms.	**Coefficient**	**5.454*****	**3.921*****	**0.608***	**-1.884**	**-2.634*****	**3.130****
	Std error	1.58	1.117	0.338	9.915	1.093	1.489
(D) Excluding seaquakes close to the coast.	**Coefficient**	**2.276*****	**2.014*****	**1.203****	**9.799**	**0.48**	**5.201*****
	Std error	0.873	0.706	0.519	9.178	0.722	1.735
(E) Constrained instruments.	**Coefficient**	**2.557****	**2.232*****	**1.227*****	**-2.895**	**0.073**	**4.188****
	Std error	1.12	0.762	0.452	10.19	0.877	1.645
(F) Excluding landlocked countries.	**Coefficient**	**4.601*****	**2.752*****	**1.345*****	**4.684**	**2.439**	**5.018**
	Std error	0.997	0.717	0.271	3.951	2.183	3.172
(G) Excluding provinces	**Coefficient**	**2.337*****	**1.704*****	**1.186*****	**0.008**	**0.186**	**6.514*****
	Std error	0 .920	0. 6537	0.201	4.729	1.847	2.163

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

Additional results

- Estimations also point to a positive effect of email use on the (ln) **number of production workers** and **non-production workers**, with a stronger effect on the former.
- Results are robust to alternative instrument calibrations:
  - ❑ Seaquake freq 100-1000km x Ln dist infra (best instrument but no Hansen test)
  - ❑ Seaquake freq [0-100km; 100-500km; 500-1000km] x Ln dist infra
  - ❑ Seaquake freq 100-1000km x Ln dist [SMC; IXP]
- Results are robust to alternative var. of Internet access: How access to telecommunications is an obstacle to firm operations? (no obstacle ➔ very severe obstacle).
- Results are robust to the exclusion of firms located in capital cities from the sample.
- Results are robust to the exclusion of firms in the top 1% distributions of total sales and sales per worker.

Conclusion

- **Large effects of Internet use at the location level**, and therefore, suggests that the impact of broadband arrival is **heterogeneous within countries**.
- These positive effects appear to be mainly **driven by productivity gains** and the **services sector**.
- Our results specifically stress the **pb of a country's exposure to seismic risk** for the Internet economy's expansion and the performance of firms
- but **this conclusion can be extended to other sources of cable faults**, such as maritime activities, piracy, or other natural hazards.

Malecki (Econ Geo, 2002, p.399) on the Internet infrastructure:

"interconnection is both critical to the functioning of the Internet and the source of its greatest complications".

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Thank you!