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Fast Internet, digital vulnerabilities and firm performances in developing and transition countries

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Abstract

This paper provides city-level evidence on the impact of fast Internet on firm performances in developing and transition economies. Over the last two decades, international connectivity has been boosted by the laying of more than 300 submarine telecommunication cables (SMC). Almost all coastal developing and transition countries are henceforth plugged to the global Internet, so that the remaining structural impediments to Internet economy's growth are twofold: first the digital isolation, i.e. the gap between Internet users and the existing and often lacking terrestrial telecommunication infrastructure network; and second, the country's exposure to SMC faults.

… /…

Keywords: NICT, Submarine cables, infrastructures, telecommunications, firm performance

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…/…   We estimate the impact of Internet access on firm performance by adopting an instrumental variable (IV) approach reflecting these two digital vulnerabilities. Estimations are carried out using large a sample of firms from more than 2,600 cities in some 60 developing and transition countries. They stress that a 10% increase in the incidence of e-mail use among firms, induced by lower digital vulnerabilities, raises the firm's average annual sales by 24%, average sales per worker by 18%, and temporary employment by 15%. This result is robust to the exclusion of outliers, of exporters and big firms, of firms created after SMC arrival, and to the use of other proxies for firms' access to Internet. It therefore suggests the existence of large spillover effects of fast Internet at the local level.

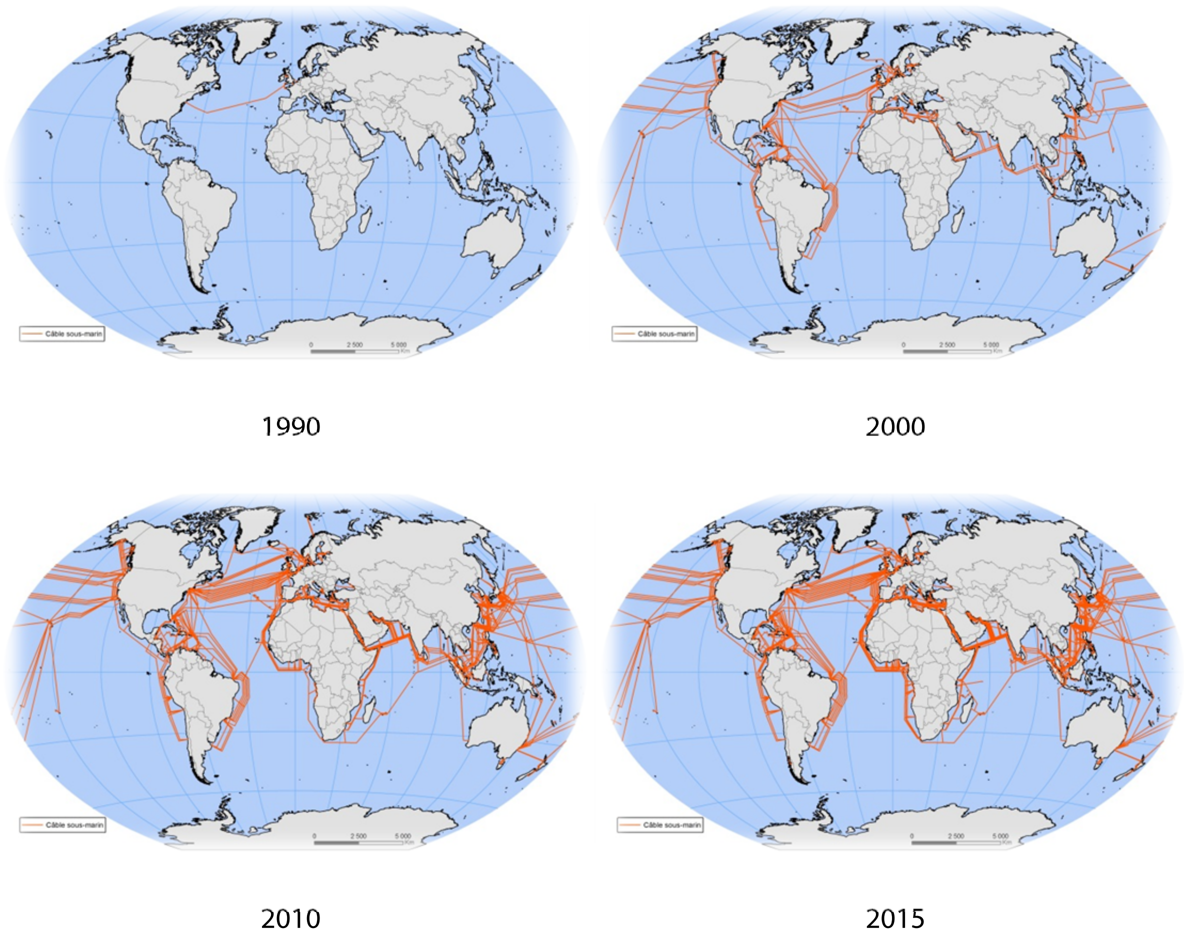
1. Introduction

Over the last decade, international connectivity underwent a dramatic improvement, promoted by the laying of 321 fiber sub-marine cables (SMC) over 1990-2015 (see figure 1). Nowadays, more than 99% of the world telecommunications – Internet contents, phone and video calls, classified diplomatic messages – passes through SMCs. The OECD pointed out in a 2013 report that "20 households with average broadband usage generate as much traffic as the entire Internet carried in 1995" (Weller and Woodcock, 2013), so that SMC networks worldwide irrigate now a USD 20.4 trillion industry, connecting 3 billion Internet users worldwide (Nyirenda and Tesfaye, 2015).

In 2016, almost all coastal developing and transition countries are plugged to the global Internet through SMCs. While fast growing Asian and south-American countries have been rapidly plugged to Northern economies, Africa has remained digitally isolated from the rest of the world until 2010. Since then, Africa's intercontinental and continental submarine infrastructure has dramatically expanded, and has been followed by a significant upturn in Internet and mobile broadband access, spurred by the impressive growth of the mobile industry.

The development of broadband infrastructures may have a positive effect on economic development through its impact on business performances. Connection to fast-Internet may first reduce transaction costs. It can make communication between market actors –sellers and customers, suppliers and sellers, producers and exporters, etc. - more fluid. In addition, connection to new countries can promote and facilitate exports and imports of firms. A higher penetration rate of fast Internet can also make it much easier to relate employers with jobseekers. This allows employers to find more easily the skills appropriate to their needs. More generally, access to fast Internet allows a very rapid access to more information and may improve labor productivity. Finally, access of firms to some online services (tax payments, custom clearance services, bank services, etc.) makes them save time and money.

Figure 1. International digital connectedness through fiber SMCs



Source: Telegeography, 2016.

Our paper studies the effect of improved access to Internet on firm outcomes, building on firm surveys and an original database on submarine and terrestrial telecommunication infrastructure deployment. Using data from the World Bank Enterprise Surveys (WBES), conducted between 2007 and 2014 over a large sample of firms in developing and transition countries, we estimate the impact of Internet access on firm operations by adopting an instrumental variable (IV) approach reflecting heterogeneities in digital vulnerabilities. Our findings stress that a lower digital vulnerability – induced by a lower digital isolation and a lower exposure to telecommunication submarine cable (SMC) faults – improves firms' access to Internet, and through this mean, boosts their sales, productivity, and the number of temporary full-time employees. More specifically, our estimates support that a 10% increase in e-mail use among firms leads to a 24% increase in firm's annual sales, an 18% in sales per worker, and a 15% in temporary employment.

The next section provides a literature review of the effect of the Internet economy on economic development. The third section explains the contribution of telecommunication infrastructure to the Internet economy. The fourth section presents our empirical strategy. The fifth section exposes our results. The last section concludes.

2. Literature review

In his seminal paper, Gordon (2012) emphasizes that the impact of the third industrial revolution, led by the penetration of computers, Internet and mobile phones, on the American labor productivity, is very limited compared to what happened in the wake of the first industrial revolution (characterized by the invention and the development of steam engines and railways) and the second one (characterized particularly by the widespread access to electricity and running water). However, a growing literature evidences a significant effect of a greater access to new technologies on economic activity in developing countries, suggesting that the Internet revolution is rather a developing countries' revolution.

In the 2000s, a first strand of the literature started to study the effect of Internet on international trade, inspired by the "Internet bubble" and the collapse that followed. In one of the first papers examining this relationship, Freund and Weinhold (2004) show that Internet expansion has encouraged trade creation in sample of 56 countries over 1997-1999. Following this study, Clarke and Wallsten (2006) use the existence of a monopoly in the Internet market as an instrument of Internet penetration in 98 developed and developing countries, and find evidence of a positive effect of Internet penetration on exports from developing countries to developed countries. Their results indicate that a one percent increase in Internet hosts increases exports from developing countries to developed countries by 0.4 percent. Focusing on service trade in 151 countries between 1990 and 2006, Choi (2010) finds that a 10 percent increase in the share of Internet users raises service trade by 0.23 percent, and that this increase has a stronger effect on service exports than service imports.

From lengthier series (1970-2013), Cette et al. (2015) examine the contribution of investments in Internet Communication Technology (ICT) on labor productivity growth in four developed countries/areas. Their results indicate that the contribution of ICT to labor productivity growth in this sample was significant over the 1995-2004 decade but has since sharply fallen, corroborating Gordon's conclusions. However, building on a Romer's endogenous growth model, Choi and Yi (2009) assume that Internet can facilitate knowledge spillovers, and by this way, may contribute to economic growth. Using a panel of 207 developed and developing countries over 1991-2000, they find that a one percent increase in Internet penetration increases economic growth by about 0.055 point on average. Examining the effect on an increase in the penetration rate of high speed Internet in 25 OECD countries, Czernich et al. (2011) get comparable results.

More recent studies focus on the micro-level effect of Internet access and usage on firm's outcomes. For example, Clarke (2008) finds that the use of the Internet by firms in Eastern Europe and Central Asia has a significant impact on their decision to exports but no effect on their intensive margin. They show that this result holds whether the firm operates in the industrial sector or in the service sector. Clarke et al. (2015) show that improved Internet increases both firm's sales growth and labor productivity, and that this effect is greater for 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 labor productivity, especially in the most productive firms of the sample. In contrast to these studies, Chowdhury and Wolf (2003) find that ICT investments in three East African countries (Kenya, Tanzania, Uganda) has no direct significant effect on SME performance but a positive effect general market expansion (measured by an index increasing with the output share sold far away from the local market). All in all, most studies point to a positive macro-level effect of Internet expansion on trade and growth in developing countries, and that this evidence is corroborated at the micro-level by the growth in firms' sales, exports and productivity resulting from increased Internet access and usage.

By examining the micro-level consequences of fast Internet infrastructures deployment in developing and transition economies, our paper is between these two strands of the literature. It is closer to the recent study of Hjort and Poulsen (2017), who examine the effect of fast Internet arrival on employment and productivity of African firms. However, our paper differs from this study by enlarging the scope of the sample to other developing and transition areas, and by controlling in our baseline model for a wider set of broadband infrastructure variables. Our contribution also lies in our identification strategy: to control for a potential endogeneity bias between Internet penetration and broadband infrastructures deployment, we instrument Internet use and firms' obstacle to telecommunications by proxies of the country structural and the firm's infrastructure gaps, and the country's exposure to seaquake-induced cable faults. Finally, our results stress the positive contribution of Internet access to firms' sales, productivity and number of temporary full-time employees, thereby extending relationships previously evidenced by Hjort and Poulsen (2017) to other non-African developing and transition countries.

3. Telecommunication infrastructures and digital vulnerabilities

In this section, we explain how the deployment of broadband submarine and terrestrial infrastructures has boosted the Internet economy. We also point out the main weaknesses of the infrastructure network in developing and transition countries: on the one hand, the terrestrial infrastructure gap between Internet users and existing broadband infrastructures; on the other hand, the network exposure to submarine cable faults. In fact, while being plugged to the global Internet through submarine telecommunication cables (SMC), developing and transition countries remain digitally vulnerable.

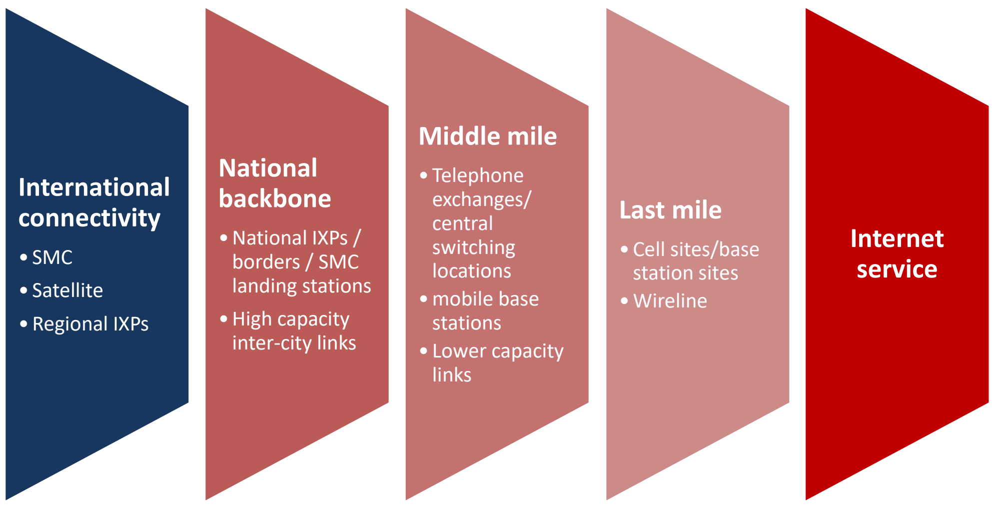
3.1. Telecommunication infrastructure deployment and the Internet access value chain

International connectivity is the first element of the Internet access value chain, presented in Figure 2. In absence of SMC, a country has three solutions to reduce international digital isolation: i) buying Internet bandwidth to a SMC-connected neighboring country, ii) using communication satellites, or iii) exchanging local and regional content with neighboring countries through a network of national and a regional Internet Exchange Points (IXPs). While the first two solutions are associated with costly and low quality Internet services (in terms of speed and Internet bandwidth), the deployment of IXPs, is a solution for local and regional connectivity only, which relies on the terrestrial infrastructure' deployment.

The laying of SMC infrastructures is therefore the first step towards the access to the global Internet, and a catalyst for subsequent investments in backbone, middle-mile, and last-mile terrestrial telecommunication infrastructures, by making them more profitable (Schumann and Kende, 2013). The number of SMCs plugging countries to the global Internet is expected to boost the Internet economy by affecting the total bandwidth available to Internet users, the cost of Internet services, the competition environment, and the country's vulnerability to cable faults. As a result, for a given regulatory framework, the greater the number of SMCs for a given country (Weller and Woodcock, 2013; Schumann and Kende, 2013; Telegeography, 2016):

- the wider the bandwidth, and the faster the Internet speed;
- the shorter the distance between Internet users, the lower the cost of Internet access[1];
- the greater the competition between cables operators, the lower Internet tariffs;
- the bigger the scale economies, the higher the incentives to extend terrestrial infrastructures and to lower Internet tariffs;
- the better the redundancy, the higher the resilience of communication networks, and the lower the vulnerability to cable faults and Internet disruptions.

Figure 2. Internet access value chain and key telecommunication infrastructures



Source: authors, adapted from Schumann and Kende (2013).

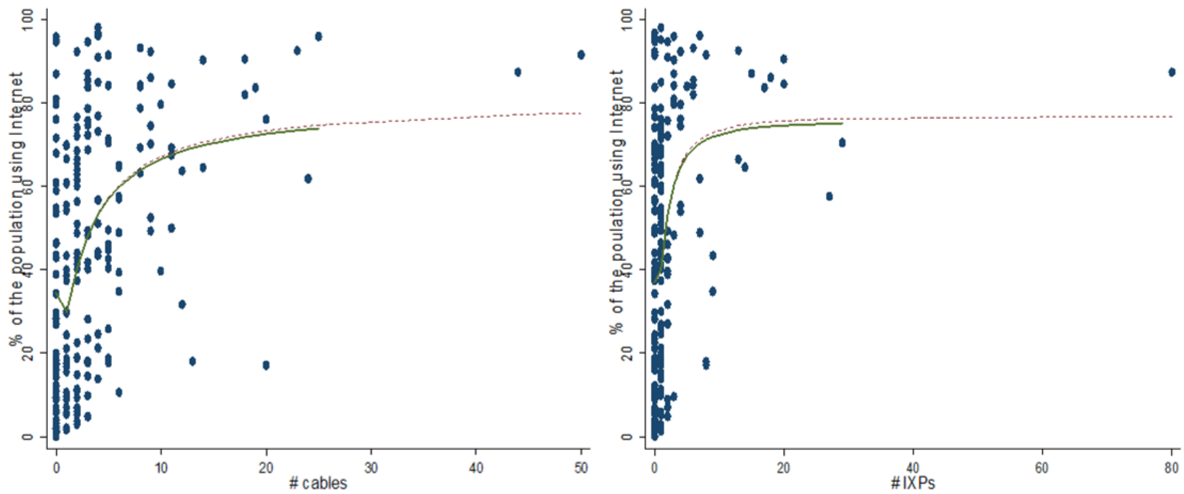
[1] A general rule states that the cost of telecommunication services is equal to the speed of Internet times the distance covered: *cost = time x distance* (Weller and Woodcock, 2013).

In addition to SMCs, Internet exchange points (IXPs) represent a key element of national and regional backbone telecommunication infrastructures, and an important source of Internet bandwidth (Weller and Woodcock, 2013; OECD, 2014; Nyirenda and Tesfaye, 2015). IXPs are national or regional Internet hubs where Internet protocol networks can exchange traffic with each other. IXPs allow reducing latency by favoring direct interconnections between countries, and saving bandwidth for international communications by keeping local traffic locally. By doing this, IXPs also enable to peer Internet traffic at low cost, which reduces the cost of providing access to Internet. Therefore, IXPs increase Internet performance and cost-efficiency, and is hence a central element of local and regional Internet eco-systems (Weller and Woodcock, 2013; OECD, 2014). Moreover, regional IXPs represent a significant part of the solution to cross-border connection issues, by allowing regional peering and transit of Internet content and adressing multilaterally regulatory barriers that would be hard to remove bilaterally.

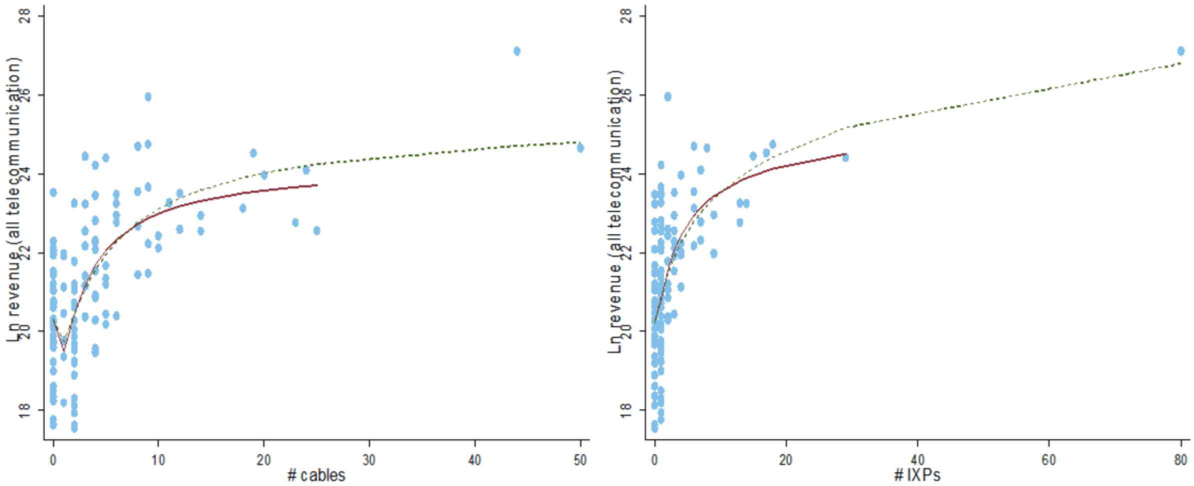
We highlight the contribution of SMCs and IXPs to the Internet economy in Graph 1. This graph shows a positive concave relationship between broadband infrastructures (alternatively measured by the number of SMCs and the number of IXPs) and Internet penetration rates on the one hand (Graph 1a) and on the telecommunication sector revenues on the other hand (Graph 1b). This graphical evidence suggests that SMC and IXP deployment is good news for the telecom industry and the whole Internet economy. However the dispersion of observations around the fitted correlation lines also suggests that this relationship relies on other characteristics of the telecommunication infrastructure.

Graph 1. Correlation between SMCs/IXPs deployment and the Internet economy, 2014.

a. % of the population using Internet



b. telecommunication sector revenues



Sources: authors. Data drawn from Telegeography (2016) and International Telecommunication Union (2016). **Samples (2014)**: % of population using Internet, 201 developed and developing countries; All telecommunication revenue, 122 developed and developing countries. The solid correlation line has been drawn excluding the outliers, while the dashed line accounts for outliers: USA (cable and IXP graphs); Great Britain (cable graph).

3.2. Digital vulnerabilities

Once countries get internationally connected through SMCs, Internet users may still face two major vulnerabilities: the digital isolation caused by a lack of telecommunication infrastructures (backbone, middle-mile or last-mile infrastructures), and the SMCs' exposure to cable faults.

The terrestrial infrastructure gap makes the geographical distance between Internet users – firms, households, and administrations – and the existing backbone infrastructure a critical determinant of users' Internet cost and service quality (Schumann and Kende, 2013). This is particularly relevant in low and middle-income countries where such infrastructure is often missing (Schumann and Kende, 2013; Bates, 2014; Nyirenda and Tesfaye, 2015). This idea is not new, as the role of geographical distance from markets or other infrastructures on business performance has already been emphasized in the literature (Dollar et al., 2006).

In 2016, most developing and emerging countries are plugged to the global Internet through SMCs, so that the most important obstacle to Internet development and the greatest challenge for policy-makers lies in the deployment of terrestrial infrastructures. In fact, low cross-border connectivity and poor national/regional terrestrial infrastructures remain the most important barriers to Internet development in low income countries, especially in the poorest ones (Nyirenda and Tesfaye, 2015; Bates, 2014). As a matter of fact, Bates (2014) stressed that, in african countries with uncompetitive telecommunication sector, "fibre connectivity in cities that are far removed from submarine cable landing stations often costs five or six times as much as it does at the landing station" (p2).

One second digital vulnerability is the SMC network's exposure to cable faults. In fact, the worldwide SMC web, upon which the whole international digital connectivity relies, is of major, geo-strategic and economic importance (Clark, 2016). According to the marine cable repair company *Global Marine Systems*, there were more than 50 cable repair operations in the Atlantic Ocean alone in 2007 (Borland, 2008). Between 2008 and 2012, data collected by Palmer-Felgate et al (2013) point that 471 cable repairs have been undertaken worldwide, geographically spread as follow (repair agreement areas are reported in Appendix E.3): 186 cable in the ACMA area (Atlantic Ocean), 115 cable in the MECMA area (Mediterranean Sea), 93 in the YZ area (Pacific Ocean, Asia side), 68 in the SEAIOCMA (2010-2011, South-east Asia and Indian Ocean) and 9 in the NAZ area (Pacific Ocean, North America side). As an illustration of economies' strong vulnerability to telecommunication SMC breaks, the simultaneous cut underwent by SEA-ME-WE 3, SEA-ME-WE 4 et FLAG[2] cables on December 19, 2008 induced a 24-hours outage and a 10-days slowdown of Internet access affecting million people in Europe, the Middle-East, south Asia, and even East-Africa, and causing a dramatic loss of Internet capacity for 14 countries[3].

In addition, there are direct costs for firms of repairing damaged cables, amounting to millions of dollars depending on cable repair frequency and length, as well as indirect economic costs, which may also rise to tens or hundreds million dollars[4]. These indirect costs are related to (Widmer et al, 2010; Clark, 2016):

- The reporting of repair costs on Internet tariffs and its consequences on Internet penetration;
- The rerouting of Internet traffic towards more expensive cable paths and its consequences on Internet capacity and tariffs;
- The disorganization of global manufacturing chains and Internet-related service provision (e.g. financial services).

Last but not least, these direct and indirect costs are amplified by delays in cable repairs. According to Palmer-Felgate et al (2013), these delays vary significantly among maintenance areas and countries and are mainly caused by: multiple outages caused by natural events such as earthquakes, ship engaged in prior repair (likely induced by multiple outages), repair permit requirement delay or operational issues.

[2] SEA-ME-WE means South East Asia-Middle East-Western Europe, and FLAG corresponds to the cable "Fiber-optic Link Around the Globe" connecting the United-Kingdom to Japan, passing through Italy, Egypt, Jordan, India, China , etc.

[3] According to the France Telecom's press release dating from the 19th of December 2008 ("Three undersea cables cut: traffic greatly disturbed between Europe and Asia/Near East zone"), the following countries have suffered from dramatic Internet disruptions: Saudi Arabia: 55% out of service; Djibouti: 71% out of service; Egypt: 52% out of service; United Arab Emirates: 68% out of service; India: 82% out of service; Lebanon: 16% out of service; Malaysia: 42% out of service; Maldives: 100% out of service; Pakistan: 51% out of service; Qatar: 73% out of service; Syria: 36% out of service; Taiwan: 39% out of service; Yemen: 38% out of service; Zambia: 62% out of service.

[4] According to Franz-Stefan Gady, the 24-hours shutdown in Pakistan, Egypt, Saudi Arabia and India, resulting from the 12/19/2008 cable cut, costed approximately 64 million dollars. See Franz-Stefan Gady, « Undersea Cables: The Achilles Heel of our Economies", the Hufftington Post, May 25 2011.

4. Empirical strategy

4.1. Baseline empirical models

4.1.1. Determinants of firm's Internet use

Our empirical analysis starts by emphasizing the contribution of the telecommunication infrastructure network to firms' access to Internet during their operations. We first examine the determinants of the firm's probability of using Internet by applying the pooled logit estimator to the following specification:

$$\Pr(internet = 1)_i = \alpha_0 + \alpha_1 X_i + \alpha_2 V_j + \alpha_3 BBI_j + \pi_s + \mu_r + \delta_t + \omega_{i,j} \quad (1)$$

Where $Internet_i$ is a proxy of firm *i*'s access to Internet; X_i controls for a set of firm-level determinants of access to Internet (the logarithm of total sales, size, age, property status, size of the city where the firm is located, the firm's share of exports, the share of external funding, the electricity constraint); V_j is a vector of key country-level controls (the population logarithm, the GDP per capita logarithm, landlockedness, democracy, education level); BBI_j is a set of broadband infrastructure variables (explained in part 4.2); and $\omega_{i,j}$ an i.i.d error term. We also include sector, region and year-of-interview fixed-effects (π_s, μ_r, δ_t). Data sources and definitions of control variables are detailed in appendix B.

4.1.2. Effect of Internet use on firm's performances

In a second step, the core of our analysis being the effect of e-mail use on firm annual sales, productivity, and employment, we conduct OLS pooled estimations of the following model:

$$y_{i,j} = \alpha + \gamma_1 Internet_{i,j} + \gamma_2 X_{i,j} + \gamma_3 V_j + \gamma_4 BBI_j + \pi_s + \mu_r + \delta_t + \varepsilon_{i,j} \quad (2)$$

Where $y_{i,j}$ is a variable of firm's *i* performance in country j, $Internet_{i,j}$ measures Internet use of firm *i* in country *j*. $X_{i,j}$ is a vector controlling for firm-level determinants of firm performances: firm's size, age, property status, size of the city where the firm is located, the firm's share of exports, the share of external funding, the electricity constraint. Country-level controls (BBI_j and V_j) are the same as in equation (1). OLS estimations of equation (2) are also conducted with firm-level data averaged at the city-level to account for spillover effects of Internet use (Paunov and Rollo, 2015) on firm's local performances.

Because there may be an endogeneity bias resulting from a two-way causality between firm outcomes and Internet use (business performance can also foster Internet use), we also run IV-2SLS estimations. However, IV estimations using firm-level data face two major concerns. The first concern is related to a possible "network effect", through which firm-level decisions (including decisions to use Internet or not) may be affected locally by other firms' decisions. In such context, orthogonality conditions may be violated as our instruments for firm's e-mail use vary at the country-level and the city-level (see section 4.3). The second concern is related to the use of a 2SLS regression framework with a firm-level binary endogenous variable, which may cause inference problems.

To sum up, we average firm-level data at the city level[5], so that i) decisions of firms that are geographically close and carrying on similar activities are taken together, ii) the dummy variable becomes a continuous variable lying between 0 and 1, and iii) we account for spillover effects of Internet use among proximate firms. We therefore the following model within a 2SLS-framework:

$$Internet_{c,j} = \alpha + \delta_1 Instruments_{c/j} + \delta_2 X_{c,j} + \delta_3 V_j + \delta_4 BBI_j + \pi_s + \mu_r + \delta_t + \varepsilon_{c,j} \quad (3)$$

$$y_{c,j} = \alpha + \gamma_1 Internet_{c,j} + \gamma_2 X_{c,j} + \gamma_3 V_j + \gamma_4 BBI_j + \pi_s + \mu_r + \delta_t + \varepsilon_{c,j} \quad (4)$$

The $Instruments_{c/j}$ vector corresponds to instrumental variables measured at the city level *c* or at the country level *j*. Control variables are the same as those specified in equation (2).

The data is detailed in part 4.2 and the identification strategy is described in part 4.3.

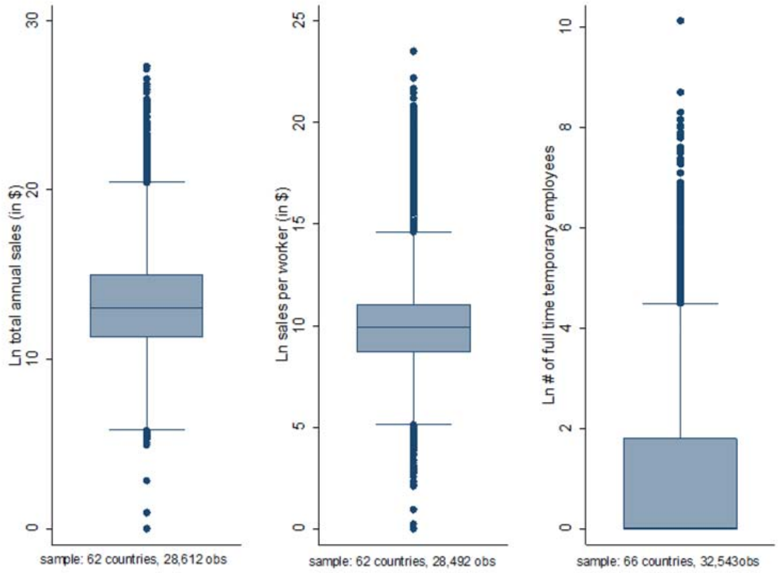
4.2. Main variables and data

4.2.1. Variables measuring firm's performance

All firm-level variables used in our model are drawn from the World Bank Enterprise Survey (WBES) dataset. These data have been collected on behalf of the World Bank through random surveys conducted in a large sample of countries among firms in the manufacturing and service sectors. These surveys consist in interviewing business owners or top managers about several topics linked to their business and to the major obstacles they face to develop their activity. To measure individual firm performance, we alternatively use the logarithm of firm's total annual sales (converted in USD), total sales per worker (converted in USD) and the number of temporary full-time employees. Graph 2 below plots the distribution of these variables.

[5] We averaged firm-level variables according to this hierarchy: country, year of interview, sector, and city.

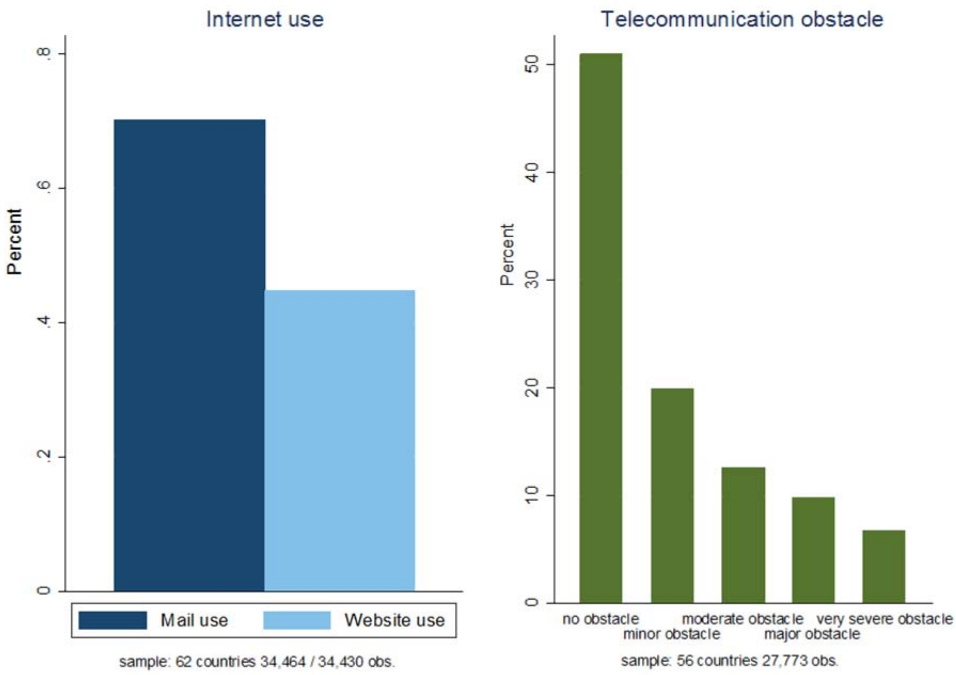
Graph 2. Distributions of firm performance dependent variables (IV samples)



4.2.2. Variables measuring Internet access

Our main variable of interest ($Internet_i$) is a dummy variable equal to one if the firm i declares having used e-mails to communicate with their clients and suppliers during the past year, drawn from the World Bank Enterprise Surveys. This variable is our main variable of interest because the use of e-mail is the most basic way to use Internet, correlated with both simple and more complex uses of the Internet. To test the robustness of our results, we also run estimations using a dummy equal to one if the firm i declares having used a website to communicate with their clients and suppliers during the past year. This website-use dummy variable is also of interest since it reflects a more specific and advanced use of the Internet by firms. We also run IV estimations using an additional categorical variable, ranging from 0 to 4, reflecting firm's perception of the telecommunication constraint. This last variable is more general but still of interest as broadband infrastructures are the vehicle of all telecommunication contents. Graph 3 below gives some insights into firm's reported experience of internet usage and telecommunication constraint.

Graph 3. Firm's access to Internet (IV samples)



4.2.3. Telecom infrastructure deployment variables

Data on Internet penetration and service quality do not fully inform on the strengths and weaknesses of the Internet economy. By contrast, data on telecommunication infrastructure deployment enlighten the great heterogeneity between countries' Internet development patterns. Based on the raw data on SMCs and IXPs deployment made available by Telegeography and complementary data sources (see Appendix A), we include in our empirical analysis a set of explanatory variables reflecting various dimensions of the telecommunication infrastructure.

Our main infrastructure variables are the number of SMCs and IXPs.[6] The importance of these two elements of the telecommunication infrastructure network has been stressed in section 3. Moreover, we also use data from Telegeography to control for additional characteristics of the infrastructure network expected to affect positively or negatively Internet outcomes (Appendix A explains the calculation principles underlying these variables):

- the country's international connectedness – that is, the number of partner countries to which a country is directly connected through SMCs – reduces the average transit costs necessary to reach a given part of the world. As a result, low international connectedness increases digital distances: international communications may pass through various countries, narrower bandwidth, and multiple operators which may charge them additional fees. Moreover, the greater the number of partners the country is directly connected to, the greater the redundancy and the lower the vulnerability to cable faults. Therefore, when a

[6] We match firm-level variables drawn from the WBES with country-level variables of infrastructure deployment by country and year of interview.

country has a multiple direct SMC connections to partner countries, Internet traffic is faster and cheaper, the bandwidth is bigger and the network is more stable (Schumann and Kende, 2013; Weller and Woodcock, 2013).

- the number of years since the first SMC activation, which may affect Internet tariffs and service quality in opposite ways: while the early arrival of SMCs allows telecom operators and Internet service provider (ISP) to exploit scale economies and to lower Internet tariffs in the long run, it may be associated with an outdated and less performing infrastructure network.
- The number of SMC owners by country, which gives information on the degree of fixed-cost sharing, on the competition environment, and on the volume of interconnection agreements. Moreover, the number of SMC owners also informs on the profitability of Internet markets, as large consortia of operators have permitted to deploy SMCs in less mature Internet markets that would not have drawn attention from operators otherwise (Sihra, 2013). Figure C.4 in Appendix C shows that large consortia of operators have been mostly implemented in sub-Saharan Africa, East Asia and Central America.

Broadband infrastructure variables and their expected effects on Internet tariffs and service quality (bandwidth, geographical coverage, stability, speed) are synthetized in Table 1 below. To illustrate the relevance of these variables, we briefly study their partial correlation with various outcomes of the Internet economy: the share of firms using e-mail during their operations (country-level), the use of e-mail by firms during their operations (firm-level), the firm's telecommunication constraint (firm-level). Table 2 reports these correlations and their significance level. Appendix C maps these different dimensions of the telecommunication infrastructure network worldwide, in 2015. While these variables of broadband infrastructure deployment are critical determinants of Internet access and its impact on the economy, they cannot be used as instrumental variables to estimate the contribution of fast Internet to the economy because of their direct effects on firm's outcomes, and a potential reverse causality from Internet practices to infrastructure development (Hjort and Poulsen, 2017). However, given their importance, they are used as control so that our identification strategy, explained below, does not suffer from omitted variable bias.

[Tables 1 & 2]

4.3. Identification strategy

To identify the effect of firms' Internet use on its performance, our IV strategy is based on three instrumental variables reflecting digital vulnerabilities in developing and transition countries, so that they affect Internet use by firms without directly influencing their individual performances:

- the **telecommunication infrastructure gap** is proxied by i) the **structural need for infrastructure**, that is, the centroid distance from the closest SMC landing station– and by ii) the **firm's need for infrastructure**, that is, the firm's distance from the closest documented key infrastructure nodes – that is, SMC landing stations or IXPs.

- the **exposure to cable faults** is proxied by the annual frequency of seaquakes which epicenters are located within a 100km or 1000km radius from SMC landing stations. Seaquakes are actually the best documented external causes of SMC faults (Carter et al, 2009).

The need for Internet infrastructures on the one hand, and the exposure to seaquake-induced cable faults on the other hand, are therefore exogenous sources of digital vulnerabilities we exploit to instrument Internet use by firms. We hereafter detail the principles underlying these instruments.

4.3.1. The structural need for telecommunication infrastructure

As evoked in section 3, the Internet user's distance to infrastructure nodes is a critical determinant of digital isolation. This infrastructure gap is a structural handicap in large and/or landlocked countries, particularly constrained in their capacity of providing good and cost-efficient Internet services over their territory (Weller and Woodcock, 2013). Unfortunately, information on terrestrial backbone infrastructures deployment is not reliable and not available for all in developing and transition countries[7]. Instead, we use information on SMC landing stations' location and proxy the structural infrastructure gap by *the country structural need for infrastructure deployment,* equal to the distance between the country's centroid and the closest SMC landing stations. This distance is intended to reflect geographical (and therefore structural) factors that will affect efforts and investments required to deploy backbone infrastructures. To reach the population, the infrastructure span has to be vaster to cover large territories such as Brazil or China, or landlocked countries such as Niger or Mali, than small and coastal countries such as Benin.

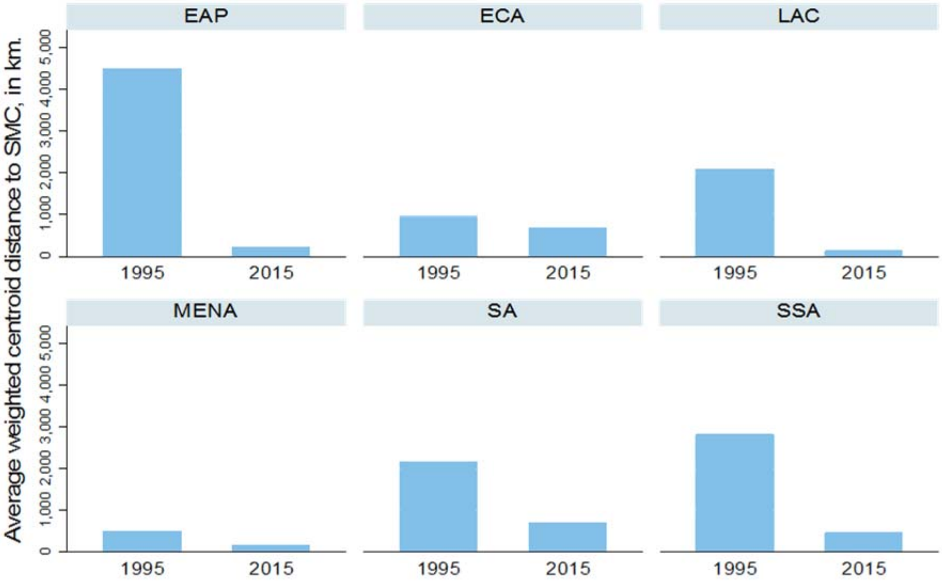
We first compute the distance from the closest SMC landing station to the country's centroid (see Appendix A), and use this variable as a proxy of the structural need for infrastructure deployment. The stronger the structural need for infrastructure deployment the more likely the infrastructure gap. For illustrative purpose, a map in appendix D represents the deployment of SMC landing stations and the centroid in China.

Graph 4 compares how average distances to SMC have evolved across regions between 2000 and 2015[8]. This figure shows that the structural need for infrastructure deployment, and thereby the infrastructure gap, has decreased in all developing regions because of the worldwide SMC network densification, but most strikingly in East-Asia and Pacific region, in Latin-America and the Caribe, and in Sub-saharan Africa. Graph 5 below plots the correlation between the structural infrastructure need and Internet penetration rates. In each region, we can observe a negative correlation between the centroid distance to SMC and Internet penetration rates.

[7] Open-source data on the backbone infrastructure in the African continent is available at https://afterfibre.nsrc.org/ (Hjort and Poulsen, 2017) but is non-exhaustive and changing from one week to another, and therefore subject to measurement errors. We did not find this type of information for other developing areas.

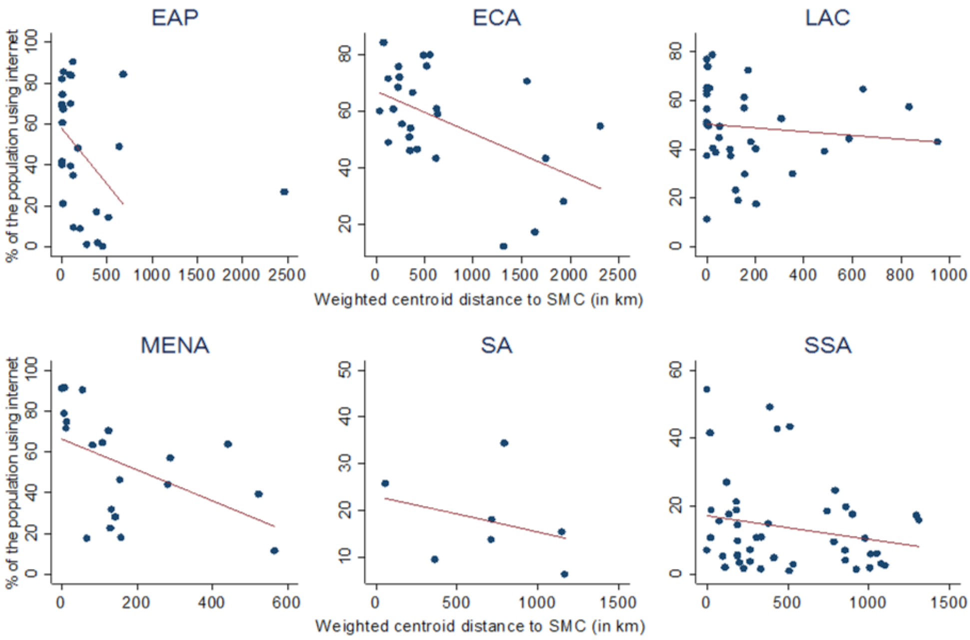
[8] This distance is calculated with respect to the closest SMC landing station located within its own frontiers. When countries do not have SMC, such as landlocked countries, the centroid distance to the closest foreign SMC landing station is instead calculated. See Appendix A.1 for the calculation principles of this variable.

Graph 4. Average regional centroid distances to SMC landing stations, 1995 and 2015.



Source: authors. Raw data on SMC landing station coordinates drawn from Telegeography. EAP: East-Asia and Pacific; SSA: Sub-Saharan Africa; MENA: Middle-East and North Africa; LAC: Latin America and Caribe; ECA: (Eastern)-Europe and Central Asia; SA: South-Asia.

Graph 5. Correlation between country centroid distances to SMC landing stations and Internet penetration rates, by developing region, in 2014.



Source: authors. Raw data on SMC landing station coordinates drawn from Telegeography. EAP: East-Asia and Pacific; SSA: Sub-Saharan Africa; MENA: Middle-East and North Africa; LAC: Latin America and Caribe; ECA: (Eastern)-Europe and Central Asia; SA: South-Asia. For the EAP area, the fitted correlation line has been drawn excluding the outlier.

4.3.2. The firm's need for telecommunication infrastructure deployment

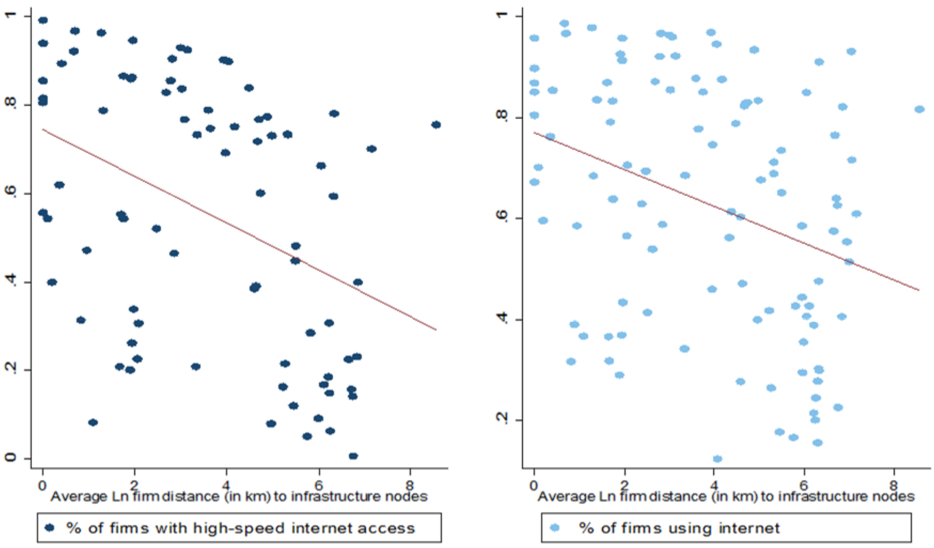
The firm's need for infrastructure deployment goes beyond the country structural need for infrastructures. This variable is the firm distance to infrastructure nodes (international and national backbone defined by SMC landing stations and IXPs location), and is measured at the city location level. This distance is an additional spatial determinant of the firm access to Internet, market access and upstream-downstream communication and performances. This firm distance to infrastructure should be considered together with the country structural infrastructure need, since the effect on Internet access of a 100km firm distance to infrastructures in Benin is likely to be different from a 100km firm distance in China, all other things being equal.

The World Bank Enterprise Surveys give information on firms' location at the municipality's level for 42,721 firms of 82 countries between 2006 and 2013. We first identified firms' city GPS coordinates. We then measure the firm (city) distance to the closest backbone infrastructure node, i.e. closest SMC landing station or IXP (See Appendix A for more details on calculation principles). For illustrative purpose, the map in appendix D represents the GPS sample city clusters of firms, and the deployment of IXPs and SMC landing stations in China.

Graph 6 reports country/city sample averages of firms' distance to infrastructure nodes, plotted against the country/city shares of firms with high speed broadband Internet connection (left-hand side graph), and the country/city shares of firms using Internet during their operations (right-hand side graph). All graphs display a negative correlation between firm's infrastructure need and firm's access to Internet.

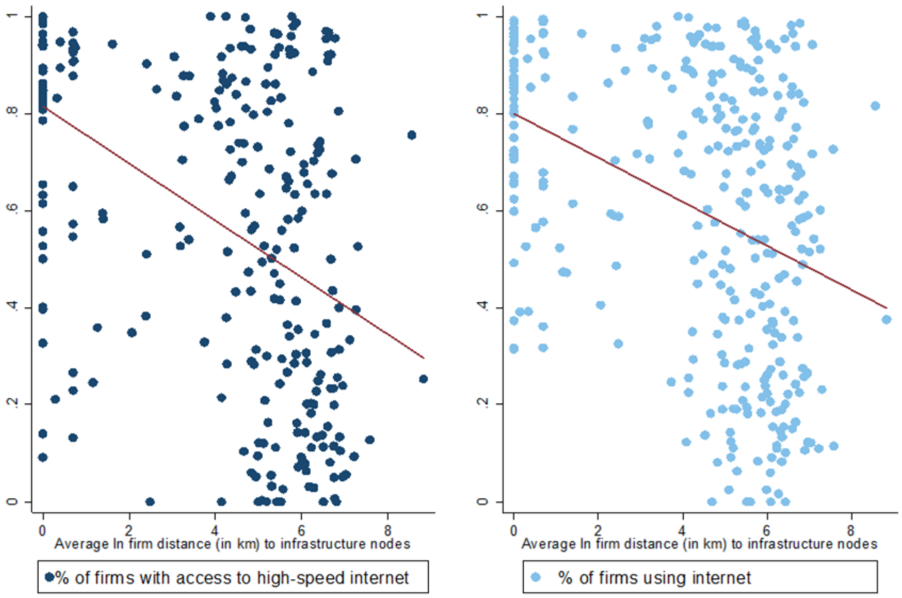
Graph 6. Country correlation between firms' distance to SMC/IXP and firms' access to Internet, country and city-level sample averages.

a. country averages



Notes: Sample weights are applied when computing country averages. **Right-hand side sample:** 108 countries, correlation = -33% (1% significant) **Left-hand side sample**: 81 countries, correlation = -41% (1% significant).

b. city averages



Notes: Sample weights are applied when computing city averages. **Right-hand side sample:** 342 cities from 108 countries, pairwise correlation = -38% (1% significant). **Left-hand side sample:** 272 cities from 81 countries, pairwise correlation = -45% (1% significant).

4.3.3. Infrastructures' exposure to seaquake-induced cable faults

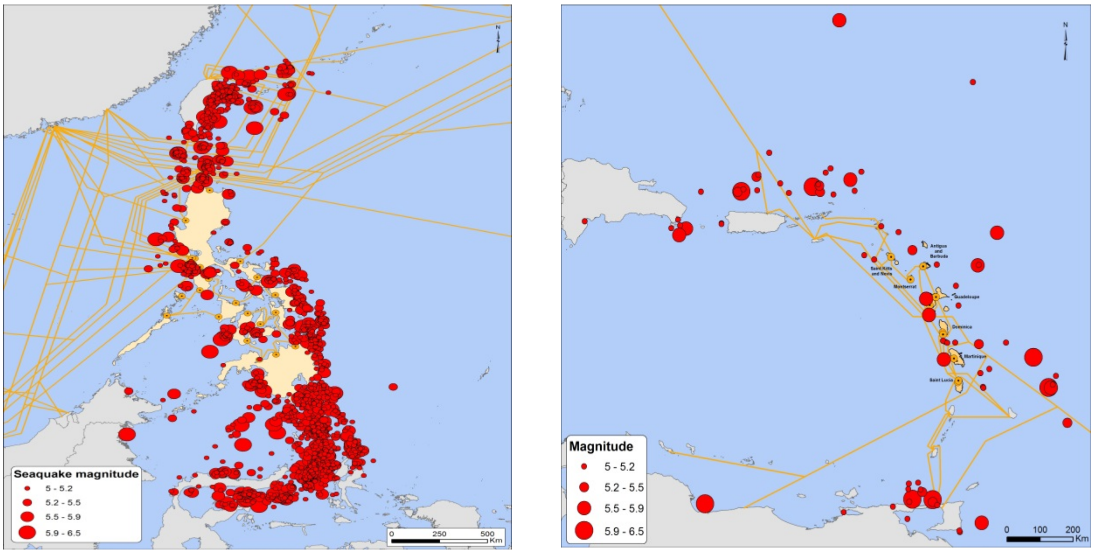
Cable faults result from multiple factors that can be grouped into five sources of external shocks (Carter et al, 2009; Clark, 2016):

- Maritime activities (fishing nets, anchors), the main source of all cable faults;
- Natural events, such as earthquakes and seaquakes, volcanic eruptions, rising sea-levels, and turbidity currents, causing in 2006 around 30% of cable breaks occurring in deep-sea water (probably more today given the dramatic densification of the undersea cable network), and the main source of multiple cable breaks;
- Shark bits and whale entanglements, although the new generation of cables is much less prone to these risks;
- Piracy and sabotages.

Among external causes of cable faults, earthquakes and seaquakes are the best documented ones. Seismic activity indeed may cause cable breaks directly or indirectly by provoking turbidities, landslides and tsunamis (Soh et al, 2004; Carter et al, 2009; Clark, 2016). It is also likely to prorogate time to repair cable by inducing multiple outages simultaneously (Palmer-Felgate et al, 2013). Last, because of their impact on the telecommunication sector revenues, the risk of cable breaks induced by the high earthquakes and seaquakes occurrence is likely to be reported on telecommunication tariffs.

Because earthquakes may cause damages to the whole economy, and therefore not only the SMC network, our identification strategy focuses more specifically on seaquake activity. We exploit information on the location, the timing, the frequency, the intensity of seaquakes occurring within a chosen distance from the SMC landing station, to build a variable of a *country exposure to cable faults*: the annual frequency of seaquakes that occurred within a radius of 1000km from the SMC landing station. To respect identification restrictions, we only count seaquakes with intensity above 5 and exclude observations with seaquake's intensity above 6.5 on the Richter scale: below 5 the seaquake might have no effect on the SMC infrastructure while above 6.5 the seaquake may induce tsunamis that may damage entire coastal areas.[9] Figures 3 represents Philippine's and the West Indies' exposure to seaquake-induced cable faults, that is, the occurrence of seaquakes from magnitude 5 to 6.5 within a 1000km radius from SMC landing stations, over 2005-2015. Appendix E maps the digital vulnerability to seismic risk, and the worldwide occurrence of seaquakes around SMC landing stations, between 1990 and 2016.

Figure 3. Seaquakes occurrence within a 1000 km radius from SMC landing stations in Philippines and the West Indies, 2005-2015.



Sources: authors. Raw data from Telegeography (2016) and Northern California Seismic Network (NCEDC).

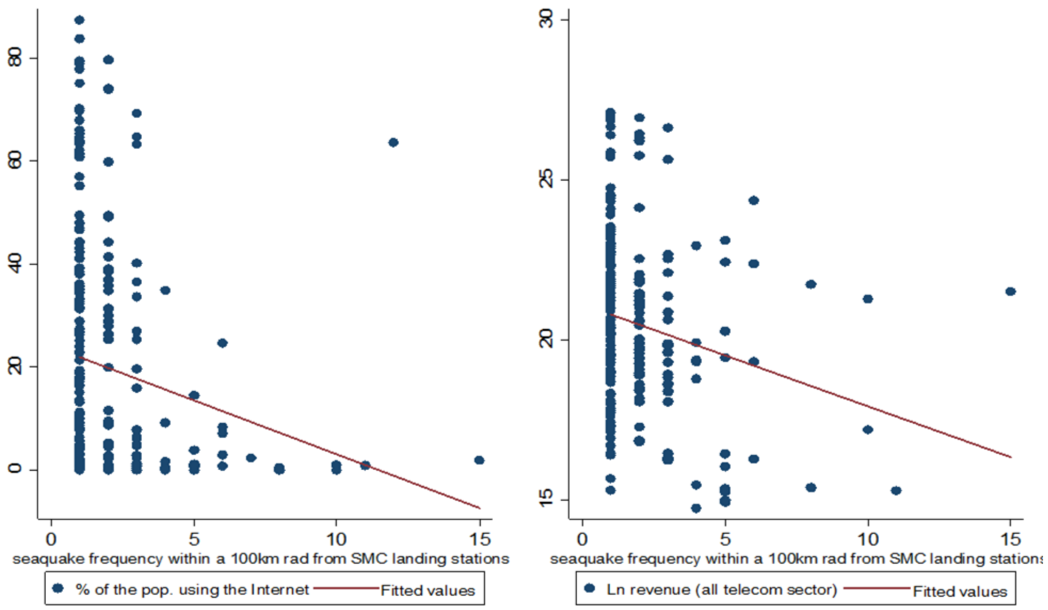
Across the world, East-Asia and Pacific countries, North-America, Russia, the Caribbean region, southwest Latin-American countries, and Middle-East and Mediterranean countries are the most exposed to this source of cable faults. Sub-Saharan Africa, Eastern south-American countries, Australia, and Canada are the least exposed regions. Graph 7a plots worldwide country Internet penetration rates and telecommunication revenues against the country annual frequencies of seaquakes (of countries having experienced at least one seaquake) and Internet penetration rates,

[9] The low 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 of seism ranging from 5.0 to 6.0 on the Richter scale. The upper bound is based on an interview 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.

over the period 1990-2014, using data from Internet Telecommunication Union on internet penetration. Graph 7b plots the country/city sample shares of firms with Internet access against the country annual frequencies of seaquakes (of countries having experienced at least one seaquake), using data from the World Bank Enterprise Surveys (WBES). All graphs display a negative correlation between the annual occurrence of seaquakes and Internet outcomes.

To sum up, the rapid deployment of submarine telecommunication infrastructure worldwide had a huge impact on Internet development and is hastening the “digital revolution” in many low and middle-income countries. Since most coastal countries are now connected to the global Internet through submarine cables, the digitalization of developing and transition economies faces two major infrastructure-related vulnerabilities, stemming from structural factors[10]: on the one hand, the terrestrial infrastructure gap, especially in large and/or landlocked countries; and on the other hand, economies’ exposure to cable faults. Our empirical strategy exploits heterogeneities in the strength of these two constraints to estimate the effect of Internet access on firm performances.

Graph 7a. Graphical correlation between annual seaquake frequency and Internet outcomes, worldwide evidence, 1990-2014.

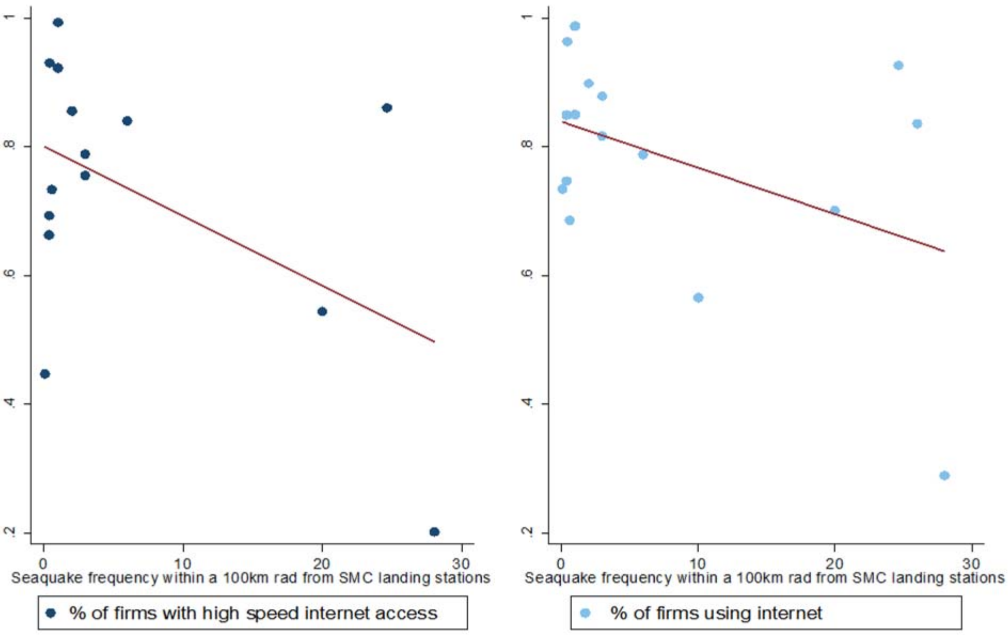


Left-hand side sample: 242 observations from 60 developed and developing countries, correlation = -17% (1% significant). **Left-hand side sample:** 211 observations from 58 developed and developing countries, correlation = -22% (1% significant). Graph correlation plots exclude Japan (outlier), and countries that do not experienced seaquakes within a 100km radius from SMC landing stations. Data sources: raw data from ITU (2016) for Internet variables, raw data from Telegeography (2016) and Northern California Seismic Network (NCEDC 2014) for the seaquake variable.

[10] Undoubtedly, developed countries are now all fully connected (at the country-level, while heterogeneity may occur at the local-level) while developing countries show heterogeneity.

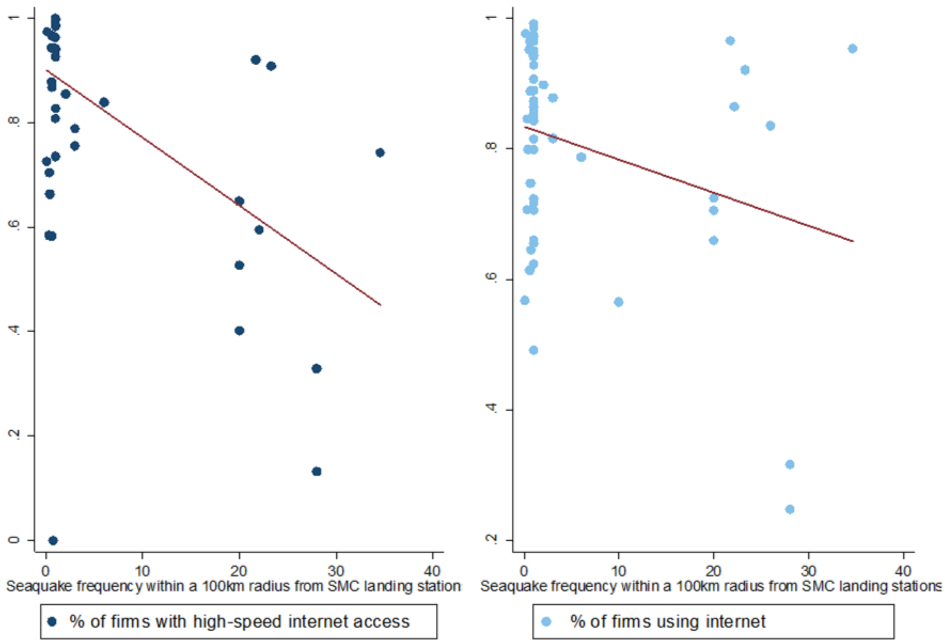
Graph 7b. Graphical correlation between annual seaquake frequency and the share of firm with access to Internet, country and city sample averages.

i. Country averages



Notes: Sample weights are applied when computing country averages. Graph correlation plots exclude countries that do not experienced seaquakes within a 100km radius from SMC landing stations. Right-hand side sample: 14 countries, correlation = -50% (10% significant). Left-hand side sample: 16 countries, correlation = -44% (10% significant).

i. City averages



Notes: Sample weights are applied when computing country averages. Graph correlation plots exclude countries that do not experienced seaquakes within a 100km radius from SMC landing stations. Right-hand side sample: 52 cities from 14 countries, correlation = -29% (5% significant). Left-hand side sample: 54 cities from 16 countries, correlation = - 51% (1% significant).

5. Empirical results

5.1. Determinants of firm's Internet use: logistic estimates

Logit estimations of the determinants of e-mail use (equation 1) in columns (1) to (4), presented in table 3 below, first highlight a positive correlation the deployment of SMCs and the use of e-mail by firms, which significance decreases as we control by macro-level determinants of Internet penetration. This suggests that the expected effect of SMC deployment on e-mail use strongly relies on country characteristics: GDP per capita, landlockness, and education. Interestingly, the deployment of IXPs is significantly and positively correlated with the use of e-mail across regressions, thereby highlighting the contribution of the broadband terrestrial network to the Internet economy. Moreover, estimates stress that the larger the period since the first cable arrival the lower the firm's probability of using e-mail during its operations, suggesting that old cables are associated with a lower technology which may constrain firm in their everyday use of Internet. Last, the number of SMC owners is negatively correlated with the probability of using e-mail, suggesting that large consortia of operators may be implemented in less mature or profitable Internet markets (see Figure C.4 in Appendix C).

We do not find such relationships when analyzing the determinants of the firm's probability of using website (columns (5) to (8). This very specific use of Internet may indeed be strongly reliant upon the sector in which firms operate. However, one paradoxical result is that the deployment of SMCs and IXPs, positively correlated with the probability of using e-mail, is positively correlated with the firm's perception of the telecommunication constraint (columns (9) to (12)). Two explanations of this correlation can be found. First, firms facing difficulties in using Internet in countries well-equipped with broadband infrastructures have a higher perception of their telecommunication constraint. Second, the deployment of broadband infrastructures may increase the digital divide between coastal and landlocked countries, between rural and urban firms, as well as the country exposure to Internet slowdowns or shutdowns.

Keeping these elements in mind, we estimate in the next section the effect of e-mail use on firm performance. The effects of website use and the telecommunication constraint are addressed in the robustness section.

[table 3]

5.2. Internet use and firm's performances: pooled OLS estimates

Pooled OLS estimates of equation (2) are presented in Table 4. They first highlight that, controlling for broadband infrastructure characteristics, the use of e-mail as communication tool by firms is positively correlated with firms' total sales, productivity, but uncorrelated with the temporary employment dependent variable. Among the BBI controls, the number of SMCs does not contribute directly, in a consistent way, to the performances of firms, while the number of IXPs is positively and significantly correlated with the temporary employment (columns (8) and (9)). The number of years since the first fiber cable activation is positively correlated with firm sales and productivity but negatively correlated with employment. The number of cable owners is positively correlated with firm sales and sales per worker in regressions using city-level data (columns (3) and (6)), but negatively related to temporary employment in regression using firm-level data (column (8)). Interestingly, OLS estimates of the effect of e-mail use on sales and productivity based on city-level averaged data (columns (3), (6), and (9)) are stronger, suggesting the existence of spill-over effects of Internet penetration among firms at the local level.

These OLS estimates provide first insights into the relationship between the Internet use by firms and their performances. They also show that some features of the broadband infrastructure directly affect firm outcomes in different ways. It is therefore necessary to control for these features to identify a causal effect of fast Internet use on firm performances. We proceed to IV estimations in the following sections.

[table 4]

5.3. Internet use and firm's performances: IV estimates

First, we transformed binary variables into continuous variables lying between 0 and 1, by averaging data at the city level. As explained earlier, doing this also allows us to address bias that could result from a "network effect" of other firms' behavior upon firm's own behavior. By following this approach, estimated effects therefore reflect the direct effect of Internet use on firm performances, as well as city-level spillover effects due to Internet penetration in the firm population.

Results of IV estimates are presented in Table 5. Second stage estimates show a strong positive and significant effect of e-mail use on annual sales, productivity, and temporary employment. According to our estimates, a 10% increase in e-mail use among the population of firms raises firm's average annual sales by almost a quarter (24%), that is, a 141,000 USD annual gain for the sample average annual revenue (589,000 USD). The same increase in e-mail use incidence leads to 18% increase in workers' productivity, (that is, 4,394 USD a year with regard to the sample average sales per worker), and a 15% increase in the number of temporary full-time employees.

First stage estimates show that the stronger the firm's need for infrastructure, i.e. the further the firm from the cable landing point, the weaker the likelihood of the firm to use Internet, the lower its performances. By this mechanism, a 10km increase in the firm distance to broadband infrastructure nodes (approximately one sample standard deviation) reduces firm's average annual sales by 6,578 USD a year, and the average sales per worker by 205 USD a year. The same increase in firm distance reduces temporary employment by 0.6%.

We find also find a negative and significant effect of the structural need for infrastructure, i.e. the centroid distance to SMC landing point, on e-mail use. Our results indeed stress that a 100km increase in the centroid distance to SMC generates a drop of 15,287 USD in average firm annual sales, and a reduction of 478 USD in the average worker's annual sales. The same increase in the centroid distance reduces temporary employment by 1.6%.

Last, the exposure to seaquake-induced cable faults, proxied by the frequency of seaquakes within a 1000km radius, has as expected a negative and significant effect on Internet use, and indirectly on firm's outcomes. Estimates stress that 10 more seaquakes a year (approximately one sample standard deviation) reduces by 1.4% e-mail use by firms, inducing an average loss of 8,551 USD a year by firm, and a 267 USD annual loss by worker.

[table 5]

5.4. Robustness checks

5.4.1- Sampling restrictions

In a first robustness check, we ensure that the more-than-proportional effect of e-mail use on firm's outcomes is not driven by the presence of outliers in the sample. We perform the Grubb test (Grubb, 1969; Stefansky, 1972) to identify outliers and rerun IV-estimations of equation (2) by excluding them from the sample. Results in table 6 are robust to this check, and estimated effects e-mail use on firm performances are still significant and strong.

[table 6]

Second, because there may be a location selectivity bias related to the greater mobility of big or export-oriented firms (Dollar et al., 2006), the firm's distance to telecommunication infrastructures may be endogenous. To ensure the validity of our instrument set is not affected by a location bias, we follow Dollar et al (2006) and carry out estimations on a sample restricted to small and medium non-exporting firms (see table 7). Moreover, excluding large and exporter firms also allows us to ensure that estimated effects of firms' distance to SMC landing points do not reflect the effect of distance to ports (where SMCs are often plugged). First stage estimates show that, despite these sampling restrictions, our instrument set is still valid and estimates of instruments are of similar magnitude as those of baseline IV-estimations in table 4. Second stage estimates in columns (1) to (3) evidence a positive and significant effect of e-mail use on total sales and on the number of temporary employees, but no significant effect on sales per worker. The positive impact of e-mail on sales per worker therefore seemed to be driven by large and/or exporting firms.

[table 7]

As a last check of the location bias, we run the same estimates on a sample restricted to firms created before the year the cable has been activated (table 8). In fact, the location bias is very unlikely for firms that have chosen their location before SMC arrival. Our results confirm the positive and significant effect of e-mail use on firm sales, productivity, and employment. The magnitude of these effects lies within the same range as previous estimates in table 4.

[table 8]

5.4.2- Alternative variables of interest

In a last robustness check, we estimate the effect of fast Internet on firm outcomes, using alternative proxies of firm's Internet access: a dummy variable equal to 1 if the firm communicates with its clients and suppliers via website, and a categorical variable ranging from 0 to 4 of the firm perception of the telecommunication constraint. We apply the same IV framework based on city-level averaged data. Results, in columns (1) to (3) of table 9, support a positive and significant effect of website use by firms on their sales, productivity, and employment level. These estimates are of similar magnitude as estimates of the effect of e-mail use on firm's outcomes. First stage estimates in columns (1) to (3) stress that, while the distance to infrastructure matters for firms using websites, the exposure to SMC faults does not seem to be constraint. However, results in columns (4) and (5) stress that a greater centroid distance to SMCs, as well as a greater exposure to SMC cable faults, increases the firm's telecommunication constraint, and that this constraint results in lower sales and lower sales per worker.

[table 9]

To sum up, IV estimations put in evidence the positive contribution of NICT to firms' performances. An increased used of e-mail and website, and a lower telecommunication constraint are found in a consistent way to boost sales, productivity, and temporary employment. These estimations point out the contribution of the maritime and terrestrial fast Internet infrastructure to the economy, by highlighting the concomitant digital vulnerabilities some developing countries may be subject to: in fact, in some countries, the arrival of fiber boosts the Internet economy but may have enlarged the digital divide between coastal and inland areas, and increased the economy's exposure to fiber cable breaks and Internet shutdowns. Therefore, the paradoxical positive contribution of broadband infrastructures to both Internet use and the telecommunication constraint, emphasized in table 3, finds here an explanation.

6. Conclusion

This paper provides new city-level evidence on the Internet's strong and positive contribution to firm performance in developing and transition economies. According to our estimations, a 10% increase in the use of e-mails in the population of firms raises by 24% firm's average annual sales, by 18% average sales per worker, and by 15% the average number of temporary workers.

First, exploiting an original database on telecommunication infrastructures' deployment worldwide, we show that the variety of firms' and countries' experiences of digital isolation explains the telecommunication constraint. In fact, we show that the distance to existing fibre infrastructure nodes is a critical determinant of Internet use. As a consequence, remote, landlocked countries, or countries with a large territory, face structural handicaps that may deprive them of the potential benefits of the digital revolution. According to our estimates, a 100km increase in the centroid distance to SMCs induces a 15,287 USD annual loss by firm, a 478 USD annual loss per worker.

Second, we show that even if digital isolation in various developing countries has been significantly reduced by the laying of hundreds of SMCs across the world, many countries remain highly vulnerable to cable breaks, whether they are caused by seaquakes, piracy, or fishing, or anchoring. Our results specifically stress the importance of a country exposure to seaquake-induced SMC breaks for the development of the Internet economy and the performance of firms, but the underlying mechanisms can be extended to previously-mentioned other sources of cable faults. As a matter of fact, an increase of 10 seaquakes within a 1000km radius from SMC landing points a year induces a 8,551 USD annual loss by firm, a 267 USD annual loss per worker.

IV estimations stress that the deployment of wireline telecommunication infrastructures impacts developing economies, but also creates heterogeneities in terms of digital isolation and exposure to cable breaks. In fact, our results support that these two major digital handicaps have a significant impact on firm sales, productivity, and employment by affecting Internet access during firms' operations. Therefore, by emphasizing economies' digital vulnerabilities, this paper highlights the central role of broadband infrastructure deployment in the current development process.

Tables

Table 1. Telecommunication infrastructure and its contribution to the Internet economy.

Variables	Mechanisms	Internet tariffs	Service quality
Number of SMCs	- Wider bandwidth and faster Internet speed - Shorter digital distance between Internet users - Bigger scale economies - increased competition - Greater redundancy and resilience to cable faults	-	+
Number of IXPs	- Wider bandwidth - Lower latency - Greater cost-efficiency - Greater interconnectedness	-	+
Time since first cable laying	- Scale economies	-	+
	- Technology gap	+	-
Number of cable owners	- Better international connectivity	-	+
	- Shared fixed costs	-	Undetermined
	- Increased competition	-	+
	- lower profitability/maturity of the Internet market	+	-
Number of connected partner countries	- Lower “digital distance” between countries - Greater redundancy and resilience to cable faults	-	+

Table 2. Pairwise correlations between infrastructure deployment variables, and country-level and firm-level Internet outcomes.

	% of firms using e-mails (country-level)[1]	The firm has used e-mail (firm-level)	The telecom constraint (firm-level)
# SMCs	0.17	0.13*	-0.13*
# IXPs	0.24*	0.16*	-0.04*
Connectedness	0.05	0.09*	-0.14*
Age first cable	0.30*	0.19*	-0.08*
# SMC owners	0.05	0.09*	-0.10*
Observations	189	1.0e+05	74,158

Table 3. Determinants of e-mail use.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	E-mail use - logit estimator				**Website use - logit estimator**				**Telecom obstacle - o-logit estimator**			
BBI variables												
# SMC	0.196*	0.240**	0.191*	0.129	0.170	0.211**	0.172	0.110	0.0247	0.239**	0.144	0.132
	(0.103)	(0.114)	(0.104)	(0.101)	(0.109)	(0.103)	(0.106)	(0.0950)	(0.113)	(0.102)	(0.105)	(0.100)
# IXP	0.0797***	0.0800***	0.0694***	0.0755***	-0.0072	-0.009	-0.019	-0.024	0.0626***	0.0577***	0.080***	0.0937***
	(0.0178)	(0.0170)	(0.0180)	(0.0180)	(0.016)	(0.0158)	(0.0172)	(0.0179)	(0.0222)	(0.0217)	(0.023)	(0.0225)
Connectedness	0.0380***	0.0228	0.0270	0.0261	-0.0034	-0.0168	-0.014	-0.003	-0.0283**	0.00626	0.0165	0.00869
	(0.0147)	(0.0161)	(0.0196)	(0.0184)	(0.013)	(0.0131)	(0.0149)	(0.0146)	(0.0135)	(0.0133)	(0.014)	(0.0138)
Time 1st cable	-0.0447*	-0.0659**	-0.0992***	-0.0949***	0.0171	-0.0029	-0.031	-0.042*	-0.00028	-0.0631***	-0.052**	-0.0339
	(0.0265)	(0.0289)	(0.0300)	(0.0289)	(0.023)	(0.0239)	(0.0240)	(0.0233)	(0.0205)	(0.0214)	(0.024)	(0.0246)
# cable owners	-0.0383**	-0.0232	-0.0617***	-0.0463***	-0.0105	0.0013	-0.0306*	-0.033**	0.0196	-0.0223*	-0.0196	-0.0153
	(0.0151)	(0.0178)	(0.0196)	(0.0178)	(0.017)	(0.015)	(0.016)	(0.014)	(0.0163)	(0.0125)	(0.013)	(0.0127)
Firm-level determinants												
Electricity obst.		-0.00191	0.0321	0.0294		0.0857*	0.108**	0.110**		1.166***	1.170***	1.169***
		(0.0647)	(0.0665)	(0.0665)		(0.0515)	(0.0522)	(0.0519)		(0.102)	(0.104)	(0.105)
State owned		0.984**	0.959**	0.958**		0.927	0.912	0.917		-0.706	-0.697	-0.698
		(0.483)	(0.489)	(0.488)		(0.576)	(0.571)	(0.570)		(0.716)	(0.714)	(0.712)
Foreign		0.109	0.134	0.170		0.568**	0.592**	0.585**		-0.0639	-0.0731	-0.0627
		(0.252)	(0.251)	(0.228)		(0.246)	(0.249)	(0.244)		(0.170)	(0.170)	(0.170)
Age		0.0498	0.0529	0.0550		0.297***	0.297***	0.291***		0.0532	0.0540	0.0589
		(0.117)	(0.119)	(0.120)		(0.101)	(0.102)	(0.103)		(0.120)	(0.120)	(0.120)
City Size		-0.233***	-0.222***	-0.228***		-0.227***	-0.207***	-0.213***		0.00389	-0.0078	-0.00666
		(0.0611)	(0.0588)	(0.0592)		(0.0450)	(0.0449)	(0.0453)		(0.0416)	(0.043)	(0.0432)
Large size		0.539*	0.511*	0.501*		0.533***	0.496***	0.498***		0.0707	0.0735	0.0778
		(0.278)	(0.277)	(0.277)		(0.157)	(0.159)	(0.160)		(0.145)	(0.148)	(0.148)
Ext/ funding		-0.0002	-0.00069	-0.00023		0.007*	0.007*	0.007*		0.006	0.006	0.006
		(0.00467)	(0.00474)	(0.00469)		(0.004)	(0.004)	(0.004)		(0.004)	(0.004)	(0.004)
% of exports		0.0108**	0.0109**	0.0108**		0.0057**	0.0057**	0.0057**		0.008***	0.008***	0.008***
		(0.00459)	(0.00463)	(0.00464)		(0.0023)	(0.0023)	(0.0023)		(0.00215)	(0.00215)	(0.00215)
Total sales		0.288***	0.299***	0.299***		0.248***	0.263***	0.265***		-0.0961*	-0.097*	-0.0993*
		(0.0644)	(0.0625)	(0.0629)		(0.0438)	(0.0449)	(0.0449)		(0.0564)	(0.0580)	(0.0586)
GDP per cap.			0.758***	0.814***			0.603***	0.583***			0.236**	0.274***
			(0.0978)	(0.102)			(0.0791)	(0.0830)			(0.0929)	(0.0918)

Population			0.134	0.118			0.155**	0.173***			-0.0680	-0.0931
			(0.0994)	(0.0973)			(0.0623)	(0.0634)			(0.0578)	(0.0606)
Landlocked			-0.505**	-0.426*			-0.489**	-0.391*			0.525**	0.416*
			(0.230)	(0.228)			(0.196)	(0.201)			(0.229)	(0.228)
Education				0.0235***				-0.00803				0.0102
				(0.00612)				(0.00833)				(0.00627)
Democracy				-0.0103				0.0344***				-0.0374**
				(0.0153)				(0.0127)				(0.0145)
N	33392	33392	33392	33392	33344	33344	33344	33344	26657	26657	26657	26657
R^2	71	71	71	71	67	67	67	67	57	57	57	57

Note : All estimations include region, year and sector fixed effects. Standard errors are presented in parentheses: * significant at 10%, ** significant at 5%, *** significant at 1%. Standard errors are robust to heteroscedasticity and are clustered by country-year-sector-city.

Table 4. Mail use, broadband infrastructures and firm performances (OLS estimates – firm-level data and city-level averages)

	(1)	(2)	*(3) City-level*	(4)	(5)	*(6) City-level*	(7)	(8)	*(9) City-level*
	Total sales			**Sales / worker**			**Temporary employment**		
E-mail use	**0.753*** (0.134)**	**0.772*** (0.134)**	***1.015*** (0.265)***	**0.395*** (0.116)**	**0.422*** (0.116)**	***0.698*** (0.140)***	**0.137* (0.0730)**	**0.114 (0.0730)**	***-0.0462 (0.149)***
Landlocked	0.497** (0.209)	1.452*** (0.200)	*1.202*** (0.186)*	0.318 (0.211)	1.268*** (0.198)	*1.068*** (0.165)*	0.118* (0.0660)	-0.0855 (0.0687)	*0.00229 (0.0966)*
GDP per cap.	0.0119 (0.127)	-0.305* (0.156)	*-0.216 (0.181)*	-0.0684 (0.130)	-0.422*** (0.157)	*-0.274 (0.177)*	-0.109*** (0.0269)	-0.0401 (0.0272)	*-0.0626 (0.0459)*
Population	0.0335 (0.0484)	-0.153*** (0.0533)	*-0.0962* (0.0508)*	-0.0104 (0.0489)	-0.182*** (0.0530)	*-0.130*** (0.0451)*	0.0367* (0.0206)	0.0441* (0.0251)	*0.0340 (0.0406)*
Education	0.00620 (0.00509)	0.00637 (0.00476)	*-0.0004 (0.00514)*	-0.00188 (0.00483)	-0.00139 (0.00449)	*-0.0081* (0.00454)*	-0.00461* (0.00248)	-0.00273 (0.00184)	*0.0012 (0.00293)*
Democracy	0.0186 (0.0134)	-0.0195 (0.0157)	*0.0002 (0.0108)*	0.0133 (0.0140)	-0.0237 (0.0172)	*0.0043 (0.0099)*	0.0133** (0.00598)	0.00691 (0.00542)	*0.0048 (0.00831)*
State owned	-0.121 (0.268)	-0.101 (0.269)	*-0.102 (0.370)*	-0.315** (0.156)	-0.294* (0.158)	*-0.242 (0.254)*	0.459*** (0.164)	0.459*** (0.165)	*-0.0392 (0.209)*
Foreign	0.497*** (0.133)	0.521*** (0.129)	*0.228 (0.220)*	0.374** (0.152)	0.392*** (0.145)	*0.209 (0.216)*	0.0548 (0.126)	0.0614 (0.121)	*0.0243 (0.280)*
Age	0.182*** (0.0700)	0.178** (0.0702)	*0.288** (0.144)*	0.0284 (0.0595)	0.0250 (0.0599)	*0.0263 (0.0931)*	-0.0010 (0.0291)	-0.00715 (0.0292)	*-0.0566 (0.0894)*
City Size	-0.0888** (0.0450)	-0.0673 (0.0455)	*-0.167*** (0.0528)*	-0.0676* (0.0403)	-0.0414 (0.0414)	*-0.126*** (0.0437)*	0.0089 (0.0207)	-0.0183 (0.0200)	*-0.0380 (0.0372)*
Large firm	2.190*** (0.0844)	2.197*** (0.0828)	*2.353*** (0.241)*	-0.0134 (0.0758)	0.00228 (0.0742)	*0.0213 (0.172)*	0.841*** (0.0891)	0.824*** (0.0875)	*0.728*** (0.195)*

External funding	0.0121***	0.0120***	*0.0115****	0.0085***	0.0083***	*0.0101****	0.0028**	0.0031***	*0.00275*
	(0.00330)	(0.00331)	*(0.00282)*	(0.0030)	(0.0030)	*(0.00248)*	(0.00119)	(0.00115)	*(0.00301)*
Electricity obst.	0.0144	0.0104	*-0.0146*	-0.00856	-0.0163	*-0.00282*	0.0224	0.0235	*0.0242*
	(0.0296)	(0.0271)	*(0.109)*	(0.0271)	(0.0249)	*(0.0651)*	(0.0161)	(0.0161)	*(0.0500)*
% of exports	0.00459***	0.00396***	*-0.0002*	0.00119	0.0006	*-0.00446*	0.0001	0.00038	*0.0031*
	(0.00144)	(0.00142)	*(0.00389)*	(0.00116)	(0.00116)	*(0.00305)*	(0.00105)	(0.00105)	*(0.00391)*
# SMC		0.158	*-0.0350*		0.129	*-0.0518*		0.0854**	*0.0457*
		(0.110)	*(0.115)*		(0.115)	*(0.104)*		(0.0356)	*(0.0671)*
# IXP		0.0385***	*-0.00773*		0.0165	*-0.0162*		0.0460***	*0.0532****
		(0.0121)	*(0.0131)*		(0.0115)	*(0.0108)*		(0.00704)	*(0.0115)*
Connectedness		0.00809	*-0.0269**		-0.00682	*-0.0221*		0.00833	*-0.00208*
		(0.0131)	*(0.0150)*		(0.0129)	*(0.0144)*		(0.00531)	*(0.00953)*
Time 1st cable		0.0950***	*0.111****		0.115***	*0.121****		-0.0401***	*-0.0333***
		(0.0293)	*(0.0333)*		(0.0303)	*(0.0321)*		(0.00746)	*(0.0135)*
# cable owners		-0.00595	*0.0314**		0.00575	*0.0305**		-0.0104*	*0.00392*
		(0.0150)	*(0.0189)*		(0.0138)	*(0.0172)*		(0.00535)	*(0.0109)*
N	33613	33394	*3372*	33532	33315	*3369*	38582	38304	*3560*
Countries	67	67	*67*	67	67	*67*	71	71	*71*
R^2	0.358	0.376	*0.591*	0.182	0.211	*0.397*	0.155	0.162	*0.309*

Note : All estimations include region, year and sector fixed effects. Standard errors are presented in parentheses: * significant at 10%, ** significant at 5%, *** significant at 1%. Standard errors are robust to heteroscedasticity, are clustered by country-year-sector-city in OLS estimations using firm-level data, and clustered by country-year-sector in OLS estimations using city-level data.

Table 5. Mail use, digital vulnerabilities and firm performances (IV estimates – city-level averages)

	(1)	(2)	(3)
	Total sales	**Sales / worker**	**Temp. employment**
		2nd stage estimates	
E-mail use	**2.435****	**1.837****	**1.516***
	(0.960)	**(0.836)**	**(0.807)**
BBI controls			
# SMC	0.00361	-0.0701	0.0147
	(0.139)	(0.138)	(0.0654)
# IXP	0.252***	0.255***	0.0276
	(0.0593)	(0.0547)	(0.0309)
Connectedness	-0.0333	-0.0439*	0.0293**
	(0.0269)	(0.0248)	(0.0132)
Time 1st cable	0.173***	0.187***	-0.0287*
	(0.0425)	(0.0424)	(0.0161)
# of cable owners	0.0422	0.0535**	-0.0210**
	(0.0258)	(0.0251)	(0.00999)
Macro controls			
Landlocked	2.121***	1.949***	-0.298**
	(0.280)	(0.277)	(0.119)
GDP per cap.	-0.554**	-0.578***	-0.230**
	(0.231)	(0.220)	(0.0917)
Population	-0.423***	-0.447***	-0.0458
	(0.104)	(0.107)	(0.0507)
Education	0.00469	-0.00328	-0.00365
	(0.00672)	(0.00673)	(0.00423)
Democracy	-0.0634***	-0.0633***	-0.00361
	(0.0189)	(0.0183)	(0.00943)
Firm controls			
State owned	-0.413	-0.524	-0.323
	(0.495)	(0.348)	(0.404)
Foreign	-0.166	-0.121	-0.343
	(0.312)	(0.320)	(0.387)
Age	0.150	-0.0693	-0.0832
	(0.186)	(0.114)	(0.136)
City Size	-0.0162	-0.00181	0.00233
	(0.0576)	(0.0571)	(0.0444)
External funding	0.0155***	0.0146***	0.00659*
	(0.00315)	(0.00288)	(0.00341)
Big firm	2.128***	-0.115	0.424*
	(0.286)	(0.225)	(0.257)
Electricity obstacle	0.108	0.0941	0.0508
	(0.135)	(0.0839)	(0.0576)
% of direct/indirect exports	0.00106	-0.00449	0.00351
	(0.00385)	(0.00328)	(0.00476)

	(1)	(2)	(3)
		1st stage estimates Mail use	
Instruments			
Firm distance to SMC / IXP	**-0.016****	**-0.016****	**-0.013*****
	(0.006)	**(0.006)**	**(0.005)**
Centroid distance to SMC	**-0.050*****	**-0.050*****	**-0.050*****
	(0.018)	**(0.018)**	**(0.018)**
Seaquakes freq., 1000km rad.	**-0.004*****	**-0.004*****	**-0.002**
	(0.002)	**(0.002)**	**(0.002)**
BBI controls			
# SMC	-0.001	-0.001	0.024
	(0.025)	(0.025)	(0.021)
# IXP	-0.009	-0.009	0.010
	(0.010)	(0.010)	(0.007)
Connectedness	0.004	0.004	0.002
	(0.005)	(0.005)	(0.005)
Time 1st cable	-0.019***	-0.019***	-0.009*
	(0.006)	(0.006)	(0.005)
# of cable owners	0.000	0.000	-0.004
	(0.004)	(0.004)	(0.004)
Macro controls			
Landlocked	0.076***	0.076***	0.092***
	(0.040)	(0.040)	(0.029)
GDP per cap.	0.103***	0.103***	0.095***
	(0.017)	(0.017)	(0.015)
Population	0.080***	0.080***	0.045**
	(0.021)	(0.021)	(0.019)
Education	0.004**	0.004**	0.004***
	(0.0014)	(0.0014)	(0.001)
Democracy	0.008***	0.008***	0.002
	(0.003)	(0.003)	(0.003)
Firm controls			
State owned	0.167	0.167	0.167
	(0.116)	(0.116)	(0.114)
Foreign	0.197***	0.197***	0.172***
	(0.054)	(0.054)	(0.053)
Age	0.034	0.034	0.039
	(0.036)	(0.036)	(0.036)
City Size	-0.013	-0.013	-0.016
	(0.014)	(0.014)	(0.015)
Financing	-0.002*	-0.002*	-0.0013*
	(0.001)	(0.001)	(0.0008)
Big firm	0.110*	0.110*	0.101***
	(0.058)	(0.058)	(0.057)
Electricity obstacle	-0.013	-0.013	-0.014
	(0.015)	(0.015)	(0.014)
% of direct/indirect exports	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
N	2633	2633	2630
Countries	62	62	66
Hansen test (p. value)	0.53	0.87	0.15
Weak ident. test (F-stat)	10.56***	10.53***	7.26***
Under-ident. Test (LM-stat)	26.94***	26.88***	19.19***

Note : All estimates include region, year and sector fixed effects. Standard errors are presented in parentheses: * significant at 10%, ** significant at 5%, *** significant at 1%. Firm-level variable are averaged at the country-year-sector-city level. Standard errors are robust to heteroscedasticity and are clustered by country-year-sector.

Table 6. Mail use, digital vulnerabilities and the performances of firms, excluding outliers (IV estimates, city-level averages)

	(1)	(2)	(3)
Dep. Var	Total sales	Sales per worker	Temp. employment
# outliers	*32*	*174*	*18*
		2nd stage estimates	
E-mail use	2.247**	1.125*	1.422*
	(1.034)	(0.607)	(0.786)
# outliers	*0*	*0*	*0*
All controls		Yes	
		1st stage estimates	
Firm distance to SMC / IXP	-0.016***	-0.015***	-0.013***
	(0.005)	(0.005)	(0.005)
Centroid distance to SMC	-0.050***	-0.058***	-0.050***
	(0.018)	(0.018)	(0.018)
Seaquakes freq., 1000km rad.	-0.004**	-0.005***	-0.002
	(0.002)	(0.002)	(0.002)
All controls		Yes	
Hansen test (p. value)	0.51	0.31	0.20
Weak ident. test (F-stat)	10.59***	13.81***	7.20***
Under-ident. Test (LM-stat)	26.75***	32.94***	19.061***
N	2624	2519	2787
Countries	62	62	66

Note : All estimates include region, year and sector fixed effects. Standard errors are presented in parentheses: * significant at 10%, ** significant at 5%, *** significant at 1%. Standard errors are robust to heteroscedasticity and are clustered by country-year-sector.

Table 7. Mail use, digital vulnerabilities and the performances of small and medium, non-exporting firms (IV estimates, city-level averages)

	(1)	(2)	(3)
	Total sales	Sales per worker	Temp. employment
E-mail use	1.838*	1.068	1.335*
	(1.034)	(0.852)	(0.741)
All controls		Yes	
		1st stage estimates	
Firm distance to SMC / IXP	-0.016***	-0.016***	-0.014***
	(0.005)	(0.005)	(0.005)
Centroid distance to SMC	-0.044**	-0.044**	-0.041**
	(0.018)	(0.018)	(0.020)
Seaquakes freq., 1000km rad.	-0.004*	-0.004*	-0.002
	(0.002)	(0.002)	(0.002)
All controls		Yes	
Hansen test (p. value)	0.39	0.97	0.21
Weak ident. test (F-stat)	6.56***	6.53***	5.03***
Under-ident. Test (LM-stat)	17.87***	17.81***	13.99***
N	2377	2377	2505
Countries	62	62	66

Note : All estimates include region, year and sector fixed effects. Standard errors are presented in parentheses: * significant at 10%, ** significant at 5%, *** significant at 1%. Standard errors are robust to heteroscedasticity and are clustered by country-year-sector.

Table 8. Mail use, digital vulnerabilities and firm performance - only firms created before the SMC arrival (IV estimates, city-level averages)

	(1) Total sales	(2) Sales per worker	(3) Temp. employment
E-mail use	**2.301***	**2.051****	**1.492***
	(1.252)	**(1.025)**	**(0.864)**
All controls		Yes	
		1st stage estimates	
Firm distance to SMC / IXP	-0.014***	-0.014***	-0.009*
	(0.005)	(0.005)	(0.005)
Centroid distance to SMC	-0.044***	-0.044***	-0.053**
	(0.021)	(0.021)	(0.022)
Seaquakes freq., 1000km rad.	-0.003*	-0.003*	-0.005**
	(0.002)	(0.002)	(0.002)
All controls		Yes	
Hansen test (p. value)	0.88	0.89	0.89
Weak ident. test (F-stat)	5.71***	5.71***	6.65***
Under-ident. Test (LM-stat)	16.51***	16.51***	13.16***
N	2428	2425	2559
Countries	62	62	66

Note : All estimates include region, year and sector fixed effects. Standard errors are presented in parentheses: * significant at 10%, ** significant at 5%, *** significant at 1%. Firm-level variable are averaged at the country-year-sector-city level. Standard errors are robust to heteroscedasticity and are clustered by country-year-sector.

Table 9. Website use or telecommunication obstacle, digital vulnerabilities and firm performance (IV estimates, city-level averages)

	(1)	(2)	(3)	(4)	(5)	(6)
	Total sales	Sales / worker	Employment	Total sales	Sales / worker	Employme nt
website use	2.558**	1.936**	1.616*			
	(1.219)	(0.929)	(0.847)			
Telecom. obstacle				-3.681**	-3.437**	-0.730
				(1.674)	(1.548)	(0.624)
All controls			Yes			
			1st stage estimates			
Ln Firm distance to SMC / IXP	-0.015***	-0.014***	-0.015***	0.002	0.002	0.008
	(0.005)	(0.005)	(0.005)	(0.014)	(0.014)	(0.011)
Ln centroid distance to SMC	-0.044**	-0.044**	-0.036	0.135**	0.135**	0.090
	(0.023)	(0.023)	(0.023)	(0.064)	(0.064)	(0.070)
Seaquakes freq., 1000km rad.	-0.002	-0.002	-0.000	0.014*	0.014*	0.009
	(0.002)	(0.002)	(0.002)	(0.007)	(0.007)	(0.007)
All controls			Yes			
Hansen test (p. value)	0.49	0.81	0.23	0.88	0.92	0.06
Weak ident. test (F-stat)	5.30***	5.30***	4.42***	2.81**	2.81**	1.44
Under-ident. Test (LM-stat)	14.67***	14.67***	12.28***	7.95**	7.95**	4.29
N	2631	2628	2795	2015	2015	2185
Countries	62	62	66	62	62	66

Note : All estimates include region, year and sector fixed effects. Standard errors are presented in parentheses: * significant at 10%, ** significant at 5%, *** significant at 1%. Firm-level variable are averaged at the country-year-sector-city level. Standard errors are robust to heteroscedasticity and are clustered by country-year-sector.

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Appendix A. Data collection and treatment

A.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
- The number and identity of telecom operator owners of cables

Raw data on Internet Exchange Points are drawn from 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 points and IXPs from each country are identified and located, and counted. Then, for each country, all cables related to these points and all IXPs are identified, which gives **the number of cables** and the number of IXPs variables. Finally, the set of the foreign landing points linked to these cables are finally identified, enabling the calculation of **the connectedness variable**, which counts the number of partner countries directly connected to the country of interest.

The age of the first cable is obtained by calculating the difference between the current year and the year of the first SMC activation, by country. This variable is forward-looking and can take negative values at time t when the activation year occurs at time t=k..

Using information from Telegeography on SMC ownership structure, **the number of cable owners** is calculated for each country by summing the number of cable owners associated to all SMCs laid in that country.

A.2. Infrastructure gap proxies

We compute two infrastructure gap proxies: the structural need for infrastructure deployment, and the firm need for infrastructure deployment. A distance raster map is defined from all coordinate points, which gives the distance of each firm to the nearest Internet Exchange Point.

The structural need for infrastructure deployment

Statistical inputs: SMC landing station coordinates, countries' centroid, spatial distribution of the population.

a. country with cables : from the SMC landing points of a given country, the distance from each point of its territory is calculated in the form of a raster map with the Spatial Analyst's Cost Distance tool, using the Winkel III projection. The Zonal Statistics tool then gives us the distance from centroid of the country to the closest SMC landing station.

b. country without cable : from the closest foreign SMC landing points, the distance of each terrestrial point of the world is calculated as previously.

The firm need for infrastructure deployment

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

Firms' city location coordinates (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. The firm infrastructure need is the minimum distance for the firm to reach the closest infrastructure node: either a landing station or an IXP.

A.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 do no take into account seaquakes which 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, which magnitude are between 5 and 6.5 on the Richter scale.

Appendix B. Summary statistics

IV sample: 66 countries, 2,787 city-level observations, 32,543 firm-level observations

	min	mean	max	std dev	Sources
Dependent variables					
Ln total sales (USD)	0	13.28573	27.29597	2.824788	WBES
Ln sales per worker (USD)	0	10.1028	23.51205	2.312553	
Ln # fulltime temporary workers	0	0.9409591	10.12671	1.395419	
Independent variables					
Dummy mail use	0	0.7012825	1	0.457702	WBES
Dummy website use	0	0.4469358	1	0.497183	
#Cables	0	1.830901	7	2.162687	Authors (raw data from Telegeography, Packet Clearing House, and Peering DB)
#IXPs	0	1.095315	9	1.611337	
Connectedness	0	10.42383	45	12.90558	
First cable seniority	-3	5.787405	21	6.514196	
#operators by country	0	12.23985	46	14.04888	
Ln distance firm to infrastructures	0	3.551599	7.393878	2.592437	
Ln centroid distance to SMC landing stations	2.888737	6.150347	7.805853	1.043988	
Seaquake freq. 1000km rad from SMC	0	6.705904	40	12.31735	Authors (raw data from Telegeography and the NCEDC)
Landlockness	0.3262622	1	0	0.4688513	World Bank
Ln GDP per cap	5.258385	7.310903	9.832184	1.117845	
Ln population	16.82063	21.02389	13.46996	1.608682	
Gross enrolment rate 1ary	105.3382	149.9517	53.10298	15.06023	
Polity2	2.957631	10	-7	6.041872	Polity IV
ln firm Age	0	2.642401	4.744932	0.7778525	WBES
City size	1	2.583894	5	1.260414	
% of working capital financed by external sources	0	11.52634	100	22.74581	
Dummy state owned	0	0.0172249	1	0.130110	
Dummy foreign owned	0	0.1016734	1	0.3022226	
dummy large size	0	0.1791278	1	0.3834648	
% of direct and indirect exports	0	9.72468	100	24.68762	
Electricity access obstacle	0	1.694493	4	1.477965	

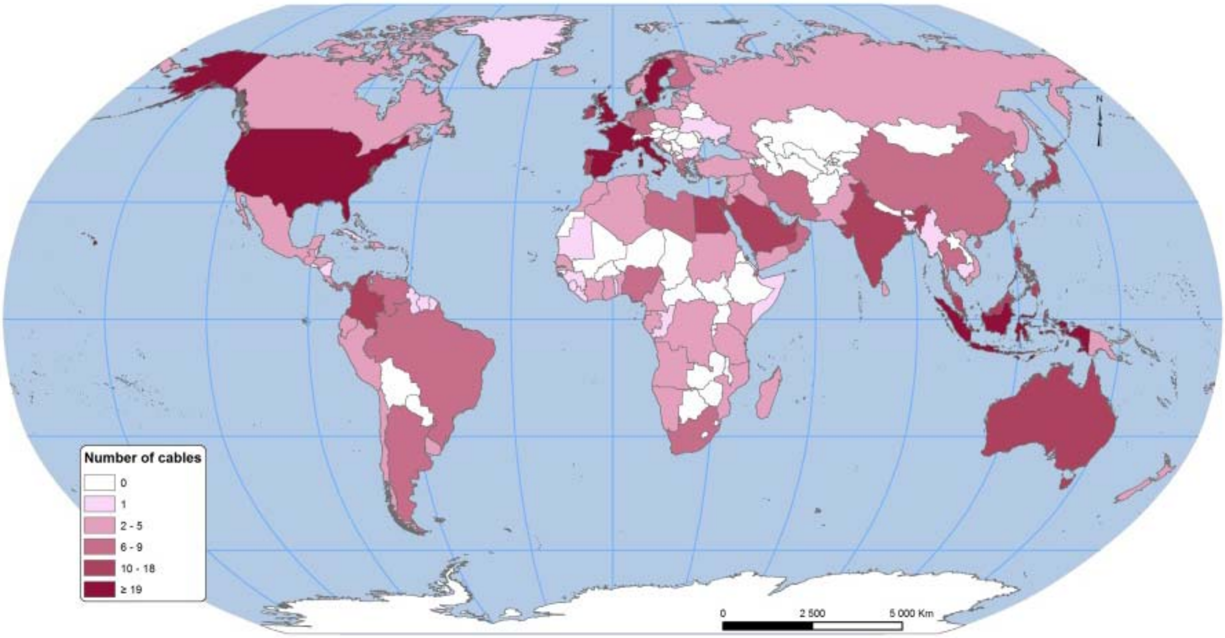
Sample composition

IV sample: 66 countries, 2,787 city-level observations, 32,543 firm-level observations

iso	2007	2009	2010	2011	2012	2013	2014	Total	iso	2007	2009	2010	2011	2012	2013	2014	Total
AFG	0	0	0	0	0	0	51	51	LSO	0	11	0	0	0	0	0	11
ALB	36	0	0	0	0	0	0	36	MDA	0	0	0	0	0	36	0	36
ARG	0	0	55	0	0	0	0	55	MDG	0	32	0	0	0	58	0	90
AZE	0	0	0	0	0	35	0	35	MLI	31	0	30	0	0	0	0	61
BEN	0	18	0	0	0	0	0	18	MNG	0	0	0	0	0	31	0	31
BFA	0	21	0	0	0	0	0	21	MOZ	35	0	0	0	0	0	0	35
BGR	35	0	0	0	0	0	0	35	MUS	0	49	0	0	0	0	0	49
BLR	0	0	0	0	0	18	0	18	MWI	0	31	0	0	0	0	0	31
BOL	0	0	33	0	0	0	0	33	NER	0	21	0	0	0	0	0	21
BTN	0	34	0	0	0	0	0	34	NIC	0	0	22	0	0	0	0	22
CAF	0	0	0	3	0	0	0	3	NPL	0	31	0	0	0	31	0	62
CHN	0	0	0	0	336	0	0	336	PAN	0	0	21	0	0	0	0	21
CIV	0	21	0	0	0	0	0	21	PER	0	0	40	0	0	0	0	40
CMR	0	29	0	0	0	0	0	29	PRY	0	0	22	0	0	0	0	22
COG	0	16	0	0	0	0	0	16	RWA	0	0	0	4	0	0	0	4
CRI	0	0	21	0	0	0	0	21	SEN	37	0	0	0	0	0	0	37
DJI	0	0	0	0	0	11	0	11	SLV	0	0	22	0	0	0	0	22
DOM	0	0	23	0	0	0	0	23	SRB	0	0	0	0	0	35	0	35
ECU	0	0	32	0	0	0	0	32	SVK	0	0	0	0	0	35	0	35
ERI	0	23	0	0	0	0	0	23	SVN	0	0	0	0	0	25	0	25
EST	0	0	0	0	0	50	0	50	TCD	0	12	0	0	0	0	0	12
ETH	0	0	0	50	0	0	0	50	TGO	0	12	0	0	0	0	0	12
GEO	0	0	0	0	0	45	0	45	TJK	0	0	0	0	0	33	0	33
GHA	36	0	0	0	0	47	0	83	TZA	0	0	0	0	0	55	0	55
GTM	0	0	22	0	0	0	0	22	UGA	0	0	0	0	0	64	0	64
GUY	0	0	2	0	0	0	0	2	UKR	0	0	0	0	0	35	0	35
HND	0	0	33	0	0	0	0	33	URY	0	0	22	0	0	0	0	22
KAZ	0	0	0	0	0	57	0	57	VEN	0	0	29	0	0	0	0	29
KGZ	0	0	0	0	0	34	0	34	VNM	0	65	0	0	0	0	0	65
LAO	0	43	0	0	46	0	0	89	YEM	0	0	55	0	0	24	0	79
LBN	0	0	0	0	0	78	0	78	ZAF	45	0	0	0	0	0	0	45
LBR	0	21	0	0	0	0	0	21	ZAR	0	0	32	0	0	43	0	75
LKA	0	0	0	73	0	0	0	73	ZMB	38	0	0	0	0	45	0	83
									Total	**293**	**490**	**516**	**130**	**382**	**925**	**51**	**2,787**

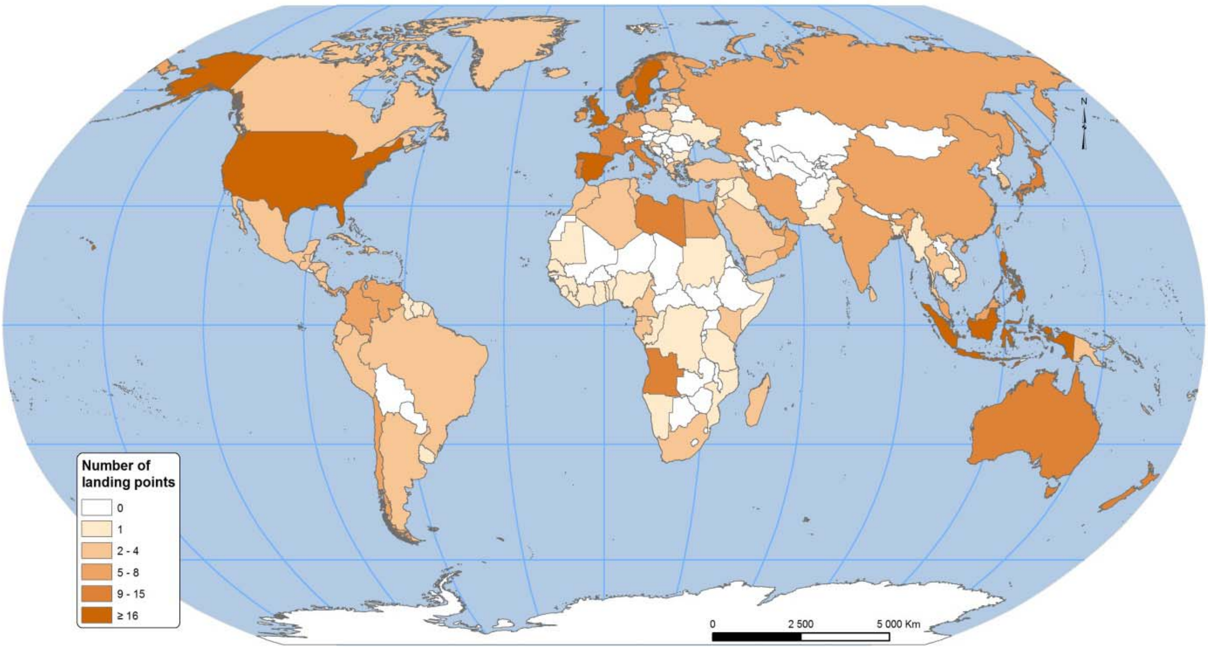
Appendix C. Infrastructure deployment maps

Figure C.1 – SMC number, by country, in 2015.



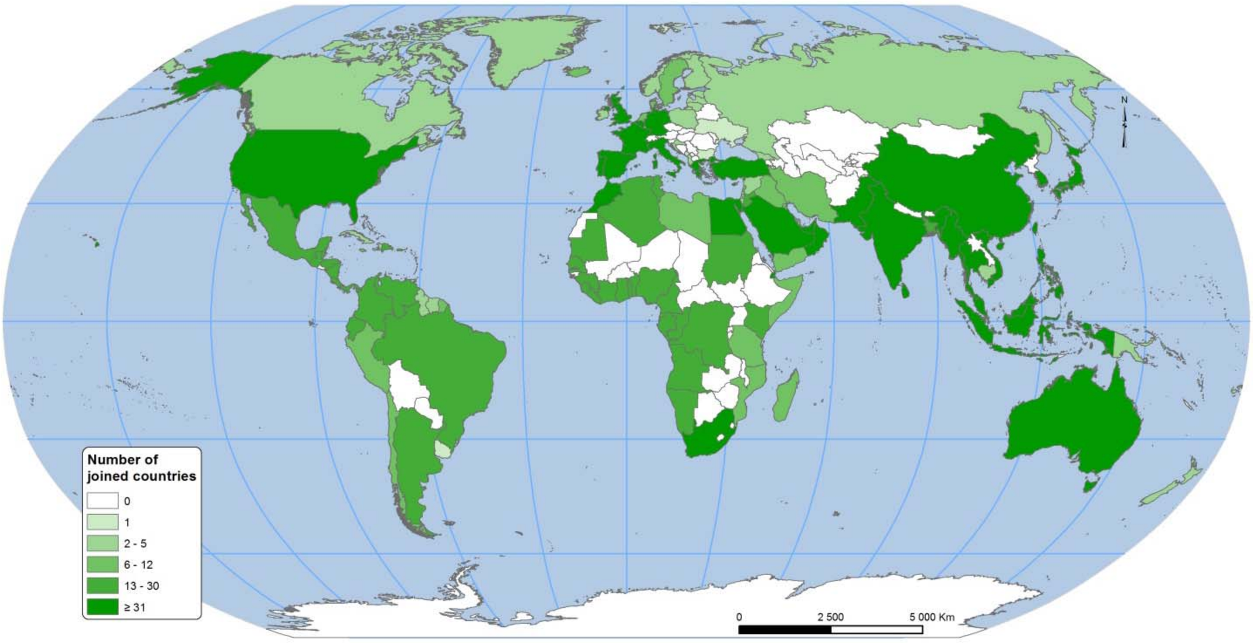
Source: data drawn from Telegeography, 2016.

Figure C.2 – IXP number, by country, in 2015.



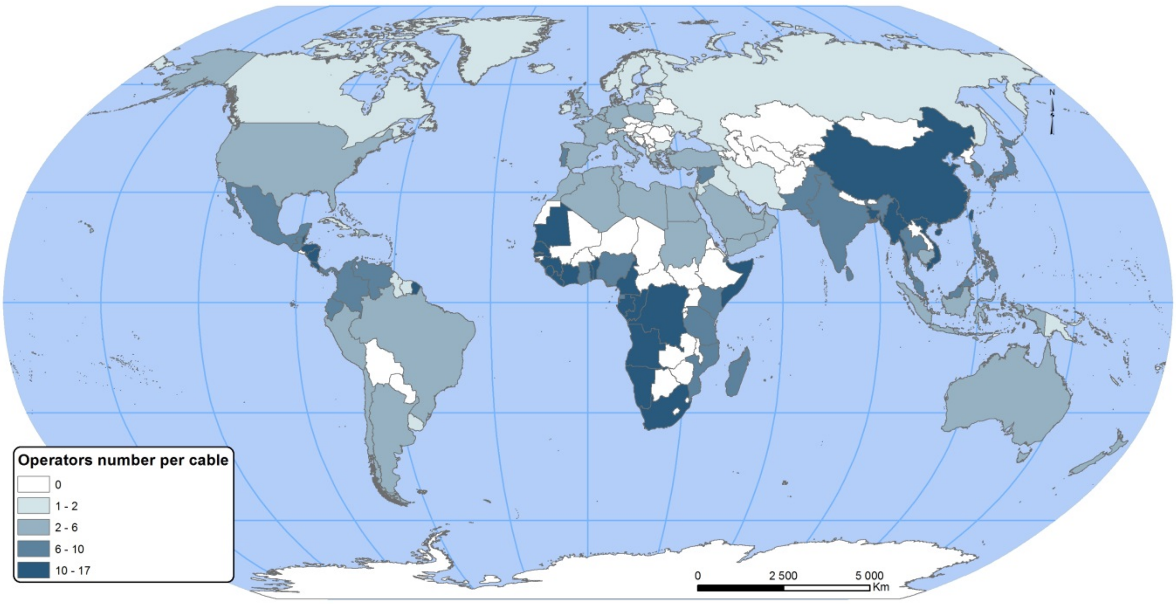
Sources: data drawn from *Telegeography*, *Packet Clearing House* (PCH) and *PeeringDB*, 2016.

Figure C.3 – International connectedness through SMCs, in 2015.



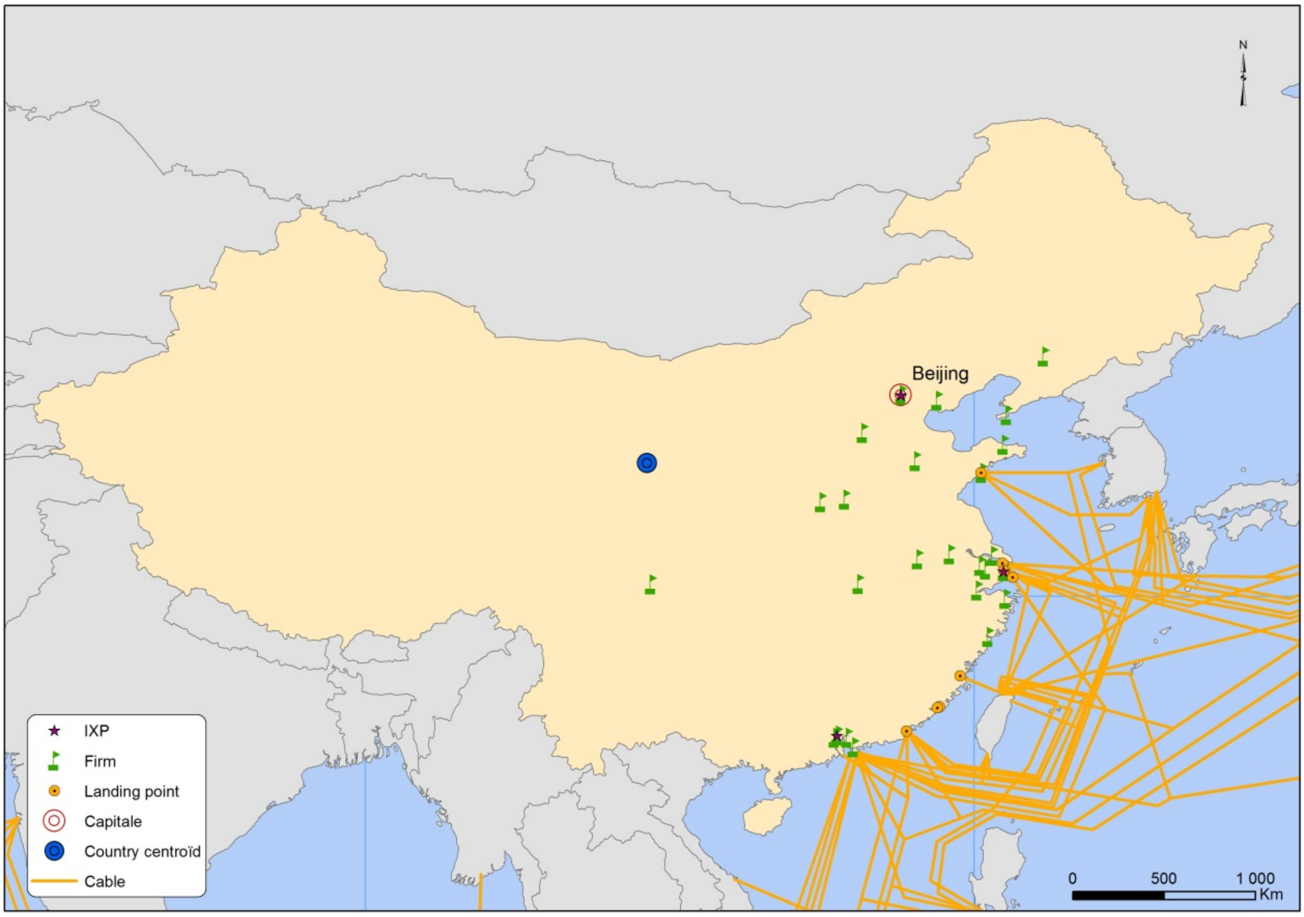
Source: data drawn from Telegeography, 2016.

Figure C.4 –Average number of cable owners by SMC, by country, in 2015.



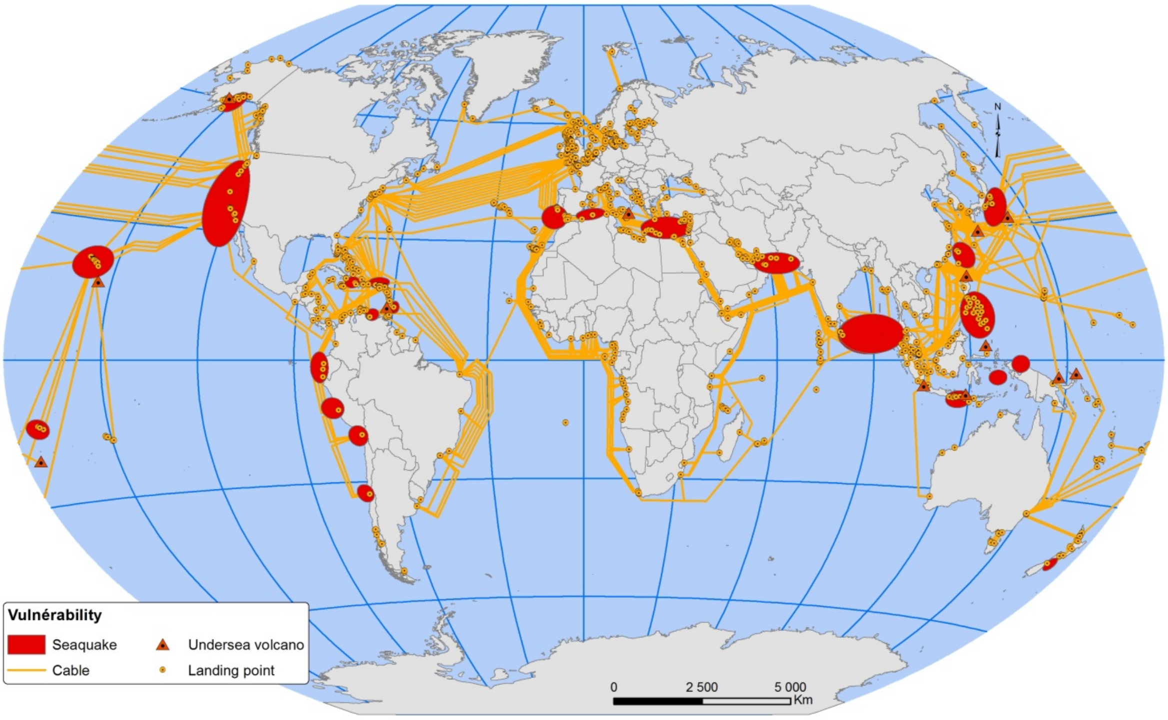
Source: data drawn from Telegeography, 2016.

Appendix D. Infrastructure deployment, centroid and firms location in China



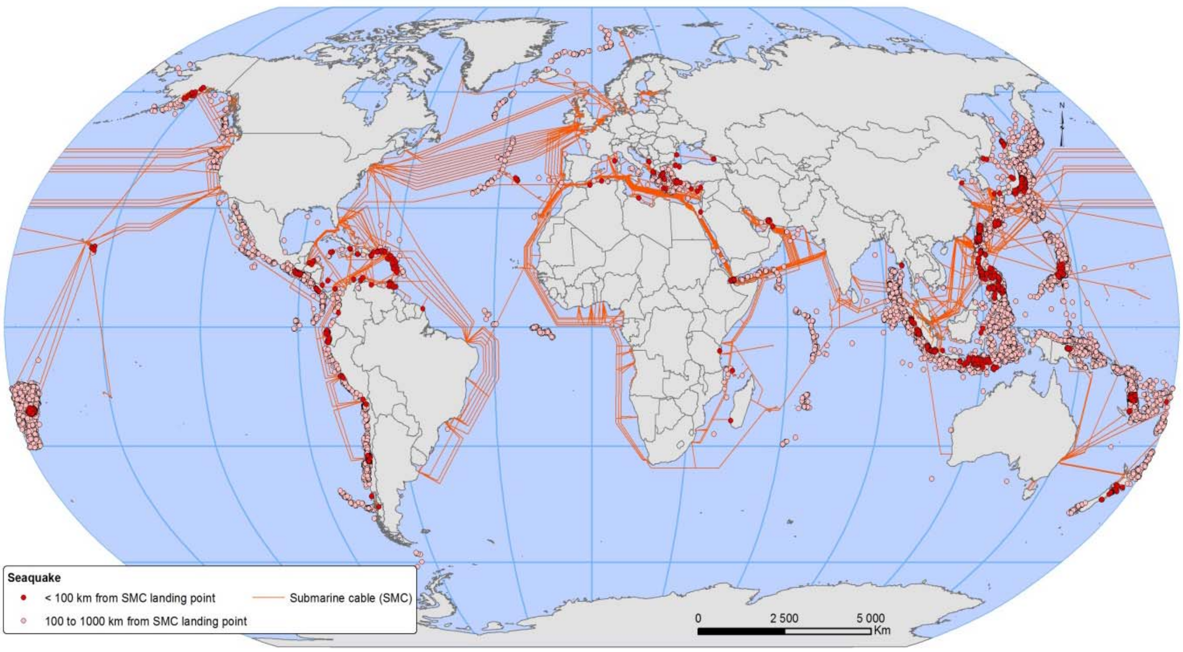
Appendix E. Digital vulnerability to seismic risk

Map E.1. Identified areas of digital vulnerability to seismic and volcanic risk



Source: vulnerability areas identified by 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. This map is not exhaustive, but based on own his knowledge of volcanic and seismic hazards and on events documented in catalogues and databases.

Map E.2. International seismic activity around SMC landing stations, 1990-2016.



Map E.3. SMC maintenance areas

Source: Global Marine Systems Ltd.

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