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The Impact of Submarine Cables on Internet Access Price, and the Role of Competition and Regulation

Joël Cariolle
Georges Vivien Houngbonon
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Davide Strusani

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Abstract

Submarine cables enable international connectivity and are essential for high-speed internet access. This paper tests their potential to improve the affordability of internet access by supporting a price drop through cost savings or increased competition intensity. The empirical framework relies on a dataset that combines the capacity of submarine cables with price data on fixed and mobile internet across 150 countries over a decade. Using a two-way fixed effects estimator, the analysis finds that the expansion of submarine cables is associated with a statistically significant drop in the price of internet access, up to 14–21 percent, depending on the technology, for every doubling of the capacity of submarine cables, and with large regional disparities. These effects stem from cost savings in the short run and tend to decline over time, concomitant with a rise in domestic telecom market concentration. The analysis also finds that these effects can be enhanced by telecom regulations, especially de-jure independence of the regulator, and the regulation of network interconnection and access, shared telecom infrastructure, and competition from international players across the broadband value chain. The main findings are robust to alternative estimation strategies, including an instrumental variable and a staggered difference in differences.

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The Impact of Submarine Cables on Internet Access Price, and the Role of Competition and Regulation*

Joël Cariolle[†], Georges Vivien Houngbonon[‡], Tarna Silue[§], Davide Strusani[¶]

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[†]Research Officer, FERDI, and University Clermont Auvergne, CNRS, IRD, CERDI, Clermont-Ferrand, France.joel.cariolle@ferdi.fr

[‡]Economist, IFC:ghoungbonon@ifc.org and Senior Fellow at the GWU Competition and Innovation Lab, corresponding author

[§]Economist, IFC:tsilue@ifc.org

[¶]Principal Economist, IFC:dstrusani@ifc.org

1 Introduction

Submarine cables (SMCs) are part of a global network of fiber optic cables that run through oceans to connect countries,[1] and therefore individuals and businesses, to the Internet. They form a crucial component of Internet access and are often considered the 'first mile' as all telecom operators need access to submarine cables to connect their customers to the global Internet. On average, 15 to 20 new submarine cables have been deployed across the globe annually over the past 30 years and a similar trend is expected to continue over the next decade.[2] Each new submarine cable typically requires several million dollars of investment and often requires additional investments in terrestrial digital infrastructure such as fiber optic cables, towers, and data centers, as well as digital innovation, entrepreneurship, and skills to benefit end-users. As such, they can support market and broader economic development in the landing countries and beyond.

Studies such as Hjort and Poulsen (2019), Simione and Li (2021), Houngbonon et al. (2022), Imbruno et al. (2022), and Cariolle and da Piedade (2023) have investigated the economy wide effects of SMCs, especially their impact on economic growth, employment, innovation, entrepreneurship, and trade. Other studies, such as Cariolle (2021) investigated the market outcomes of SMCs but focused on access to connectivity. Empirical evidence on the market outcomes of SMCs, especially the impact on price, and the role of competition and regulation is still not available. Yet, such evidence remains crucial to understanding the channels through which SMCs affect access to connectivity and generate the economy wide effects quantified in previous studies.

Anecdotal evidence abounds on how Internet access prices evolved following the arrival of major submarine cables (Appendix A). For instance, Nigeria experienced the arrival of five SMCs between 2010 and 2015.[3] These new SMCs have accelerated the growth of international Internet bandwidth used in the country, from an annual rate of 48 percent between 2010 and 2014 to 70 percent between 2015 and 2020.[4] Such an expansion in bandwidth was accompanied by a 5 percentage point drop in the price of mobile broadband over the same period.[5] Cameroon also experienced the arrival of three major SMCs during the same period, among the five which arrived in Nigeria: ACE, WACS and NCSCS. These arrivals were also associated with an ex-

[1]Some submarine cables may have some terrestrial segments.

[2]Telegeography, 2022.

[3]Glo-1 and MainOne in 2010; Africa Coast to Europe (ACE) and West Africa Cable System (WACS) in 2012, and the Nigeria Cameroon Submarine Cable System (NCSCS) in 2015.

[4]Based on bandwidth data from Telegeography.

[5]Price of 2GB of mobile broadband data in percentage of monthly income per capita - based on data from the ITU.

pansion of international bandwidth and a similar drop in mobile broadband price. In Tunisia, the arrival of a submarine cable in 2014 (Didon) was associated with a percentage drop in the price of mobile broadband.

Telecom sector research and industrial organization theories suggest two main channels through which SMCs can affect Internet access prices in the short run. First, the deployment of SMCs can result in cost savings on international connectivity for telecom operators through (i) economies of scale brought by increased international Internet bandwidth; (ii) a drop in data (re)routing cost supported by greater connectedness enabled by new SMCs; and (iii) a drop in network maintenance cost due to stronger resilience induced by the duplication of SMCs routes. Depending on the intensity of competition along the local broadband (BB) value chain, part of these cost savings can be passed onto end-users in terms of reduced price. Second, deploying SMCs can reduce barriers to entry into broadband markets, especially when the new infrastructure is shared under an open and non-discriminatory basis among retail broadband operators. In both cases, regulation can enhance these effects. These effects pertain to the short term, i.e., assuming no change in the availability and quality of connectivity for end-users. In the long run, changes in availability and quality of connectivity stemming from investment in middle and last-mile infrastructure may exert upward pressure on price.

In this paper, we assembled a dataset on SMCs to investigate their impact on price and the role of competition and regulation, controlling for several confounding factors, including the availability and quality of connectivity and market size. In particular, we sought to assess the impact of SMCs on price; how it evolves; regional heterogeneity; the biggest drivers of the impact, especially the relative influence of cost savings versus competition; and how this depends on the regulatory environment.

Our dataset covers more than 150 countries across all regions over 12 years (2008-2020) and includes detailed information on the capacity of SMCs, measured by the amount of international Internet bandwidth. We complement this information with data on the price of the typical fixed and mobile broadband Internet package, as well as market concentration indexes and 50 indicators measuring various aspects of ICT regulation. We employ a two-way fixed effects estimator, an instrumental variables estimator, as well as a staggered difference-in-differences estimation strategy.

Our estimates lend support to the hypothesis that SMCs deployment results in a drop in the price of Internet access: doubling the international bandwidth leads to up to a 14% drop in fixed BB price, and up to 21 % drop in the mobile BB price. The impact on fixed broadband price increases to 14%, 3 years post-expansion, before stabilizing around 7%-8% thereafter. On the contrary, the impact on mobile BB price drops to around 11%, 2 years post-expansion, and continues dropping towards a non-significant impact 5 years post-expansion. Except for Europe and the Middle East regions, the impact of SMCs on broadband prices was negative and statistically significant, with the lowest impact estimated for the African region, followed by Asia and Latin America where broadband markets tend to experience their biggest drop in price with the arrival of SMCs.

Our findings suggest that cost savings are the main drivers of the price effects in the short term, with some indicative role of competition in the medium term. They also suggest that regulation can be a powerful tool to increase the pass-through rate of cost savings and limit further concentration of retail broadband markets. In particular, an independent regulator, with a mandate to enforce competition through (i) reduced barriers to entry for domestic and foreign operators, (ii) shared infrastructure, including radio spectrum, (iii) regulation of interconnection and market dominance, as well as (iv) universal service provisions, and (v) consumer protection can all contribute to boost the impact of SMCs on price and alleviate its effects on market concentration.

This paper relates to the literature on digital development and the industrial organization of the telecom sector. Studies on digital development have investigated the economy wide effects of digital infrastructure, especially on GDP, jobs, productivity, innovation, entrepreneurship, and trade, but did not analyze the market outcomes of this infrastructure. A notable study is Hjort and Poulsen (2019) which exploits the gradual arrival of SMCs in Africa between 2000 and 2010 and found that changes in access to high-speed Internet post arrival of the cables led to job creation across all levels of education. A recent study conducted by Simione and Li (2021) exploited the arrival of SMCs in Africa after 2009 and found that a percentage point (pp) increase in Internet penetration induced a 0.37 pp increase in real per capita GDP growth, with increased labor productivity in the utilities, trade, and transportation sectors. These findings were supported by country case studies in Sub-Saharan Africa (SSA) (O'Connor and Anderson (2020)) which found a positive impact on GDP per capita, and an increased likelihood of being employed in fiber-connected areas. SMC connectivity can also affect trade in developing countries as suggested by findings from Imbruno et al. (2022) and Cariolle and da Piedade (2023).

Studies on the industrial organization of the telecom sector have looked, among others, at the drivers of price, especially the role of competition and regulation, but did not consider these effects in the context of infrastructure deployment. To our knowledge, the market effects of

SMCs have until now been confined to the impact on Internet penetration and delimited to the SSA context. Cariolle (2021) considered the deployment of two SMCs[6] along the Eastern and Southern African coasts in 2009-2010 as quasi-natural experiments and found that they resulted in a 3 to 5 percentage points increase in internet penetration in recipient countries. Several studies have also investigated drivers of the digital divide, especially in SSA, and identified digital infrastructure like SMCs as an important determinant (Schumann and Kende (2013); Akue-Kpakpo (2013); Bates (2014); Cariolle (2021)), and a regulatory and competition environment that until recently was not conducive to Internet affordability and quality (Wentrup et al. (2016); Gallegos et al. (2020)).

This study complements these two strands of the literature by connecting infrastructure investment with market outcomes, taking into consideration the role of competition and regulation. The remaining of the paper is organized as follows: Section 2 presents the conceptual framework along with our testable hypotheses; Section 3 presents the data and descriptive statistics, Section 4 presents the empirical framework; Section 5 reports the main results on the impact of SMCs on price, including regional effects; Section 6 discusses the role of competition and regulation; Section 7 presents some robustness checks; and Section 8 concludes.

2 Conceptual framework

2.1 Understanding SMCs and their impact on Internet access price

Determinants of Internet access prices, i.e., the price charged to individuals and businesses seeking to connect to the Internet, can be grouped into (i) supply-side factors related to the cost of international and domestic connectivity, (ii) demand-side factors related to the size of the telecommunication market, and (iii) institutional factors related to competition, which determine margin over cost, and regulations. This study focuses on supply-side factors, in relation to SMCs which primarily affect the cost of international connectivity,[7] taking into consideration demand-side and institutional factors.

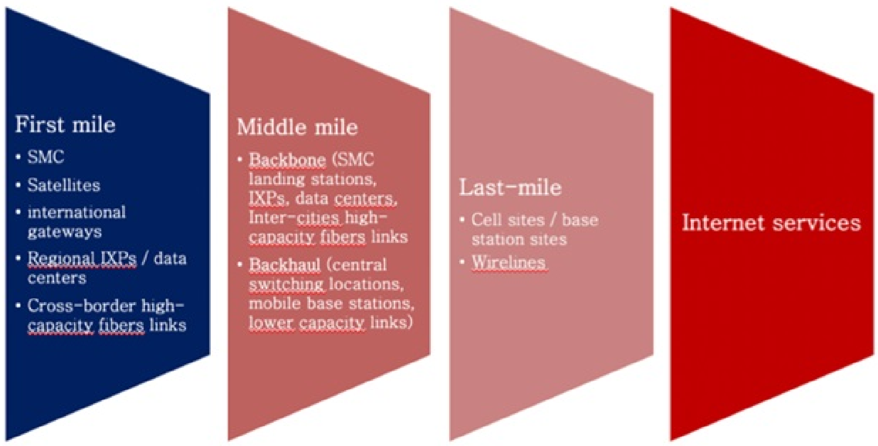
The channels through which SMCs affect Internet access prices reflect the structure of Internet infrastructure. This structure can be represented by three segments, each supported by a variety of technologies, as depicted in Figure 1: a 'first-mile' that involves international connectivity (i.e., connecting countries to the Internet), a 'middle-mile' which involves domestic

[6] EASSy and SEACOM.

[7] Other international connectivity infrastructure such satellites could be considered, but they carry less than 5 percent of international Internet traffic according to D'Andrea and Limodio (2019), based on the testimony of D. Burnett before the Senate Foreign Relations Committee on the United Nations Law of the Sea Convention.

connectivity (i.e., connecting large cities and communities to the Internet), and a 'last-mile' which involves end-users access to the Internet (i.e., connecting individuals, households and businesses to the Internet).

Figure 1: **A REPRESENTATION OF INTERNET INFRASTRUCTURE**



Source: Adapted from Cariolle (2021) and Schumann and Kende (2013)

The structure of Internet infrastructure means that SMCs can affect Internet access prices both in the short term and in the medium term. In the short term, the arrival of SMCs does not affect investment in middle and last-mile Internet infrastructure,[8] but rather reduces the cost of access to international connectivity for national telecom operators through the following three channels (Figure 2):

- **Scale economies** in international connectivity as new SMCs come with high capacity and, therefore, enable network operators to carry higher Internet traffic at the same cost.
- **Savings on (re)routing costs** as new SMCs increase international connectedness and enable network operators to bypass third countries and, therefore, save the associated routing cost. For instance, an operator in country A may have to pay a routing cost to a carrier in country B to reach country C. A new SMC connecting country A to C would allow the operator to save on that routing cost.
- **Savings on maintenance costs** as new SMCs can provide redundancy and, therefore, strengthen network resilience (Weller and Woodcock (2013), Cariolle (2018, 2021))[9] and

[8]On some occasions, companies may undertake investments in middle and last-mile infrastructure once the arrival of an SMC is announced. However, the roll out of this infrastructure takes time and there is limited evidence on whether they are completed before the SMCs.

[9]Resilience is reflected by three particular aspects of the telecommunications network functioning: fault-tolerance permitted by greater network redundancy, survivability permitted by a greater network diversity, and disruption tolerance permitted by a greater network connectivity (Sterbenz et al. (2014).

avert disruptions in international connectivity that would require maintenance by network operators.

There are two ways in which these cost reductions can affect Internet access prices:

- **Direct pass-through**, i.e., telecom operators would pass through part of the cost savings to end-users. However, the pass-through rate would depend on the regulation of bottleneck infrastructure in the middle and last mile, and the intensity of competition in the market for Internet access services. Middle and last-mile Internet infrastructure typically entail bottleneck infrastructure called backbone and backhaul or metro network that are owned by a single operator which may also be active in the retail market and, as a result, have an incentive to discriminate against competitors in the retail markets. Regulations on infrastructure sharing are crucial to enable open access to this infrastructure on a non-discriminatory basis.

- **Indirect pass-through** via increased competition in the retail connectivity market as reduced cost of access to international connectivity lowers barriers to entry for retail network operators,[10] thereby inducing a price drop. However, regulation is here again key to support such an outcome. For instance, a new SMC which is exclusively used by a vertically integrated dominant telecom operator would not reduce the barrier to entry. Regulation can mandate access to the SMC and, therefore, enable the expansion of competitors.

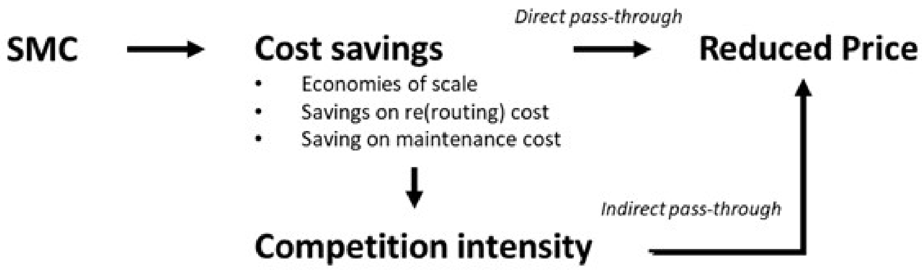
In the medium term, the arrival of SMCs would result in improved quality of Internet access by inducing investment in middle and last-mile infrastructure. For instance, in a competitive environment, network operators would upgrade the capacity of middle and last-mile infrastructure such as data centers, towers, and domestic fiber optic networks to respond to the demand for Internet traffic induced by the short-term drop in price. These investments can improve internet quality and availability and exert upward pressure on prices in the medium term.

In sum, SMCs are expected to exert a direct downward pressure on broadband price by reducing the costs of internet provision, and an indirect one by fostering competition. In the longer run, an upward price pressure, reflecting a greater internet quality and resulting from greater investment and innovation processes, might be exerted and also promoted through greater competition. While the former mechanism is termed a "cost-reduction effect", the latter one is termed the "quality effect" of SMC rollout. These mechanisms should be affected by regula-

[10]Entry refers to the establishment of a new network operator serving end-users, or the expansion of an existing operator in new geographical markets (cities) or new product lines.

tions, preventing excessive market power, protecting internet users' rights, and ensuring internet coverage.

Figure 2: **THE SHORT-TERM IMPACT OF SMCS ON PRICE**



Source: Authors.

2.2 Testable hypotheses

From the above, we derive the following potential outcomes of the arrival of SMCs which will be tested empirically.

- **Short-term effects:**
  - **Reduced price of Internet access**, derived from cost savings and/or change in competition intensity. The main channel of impact will be assessed by estimating the impact of SMCs on competition intensity.
  - **Market structure.** Increased capacity of international connectivity would result in reduced market concentration provided that it comes with increased competition along the broadband value chain or a regulatory framework that enables open access to international Internet bandwidth for small operators under a non-discriminatory basis.
- **Medium-term effects:**
  - **Moderate price reduction.** Quality improvement over the medium term means that SMCs would result in reduced prices in the short term with a more moderate impact in the medium term. Price would drop in the initial years post-arrival of SMCs, but quickly stabilize or potentially reverse upward.
  - **Increased competition intensity** supported by regulatory reforms or technological innovation that support entry or expansion of smaller firms.

3 Data and descriptive statistics

We built a country-level panel dataset covering 150 countries for which price data was available over the following period: 2008-2021 for fixed broadband, and 2012-2021 for mobile broadband. Our dataset includes data on price, SMCs, competition, and regulation, as well as several variables used as controls in the econometric modeling. Definitions and sources of variables are described in Table 1. Summary statistics are reported in Table 2, while correlation matrices are presented in Tables 3 and 4 in the Appendix.

3.1 Price data

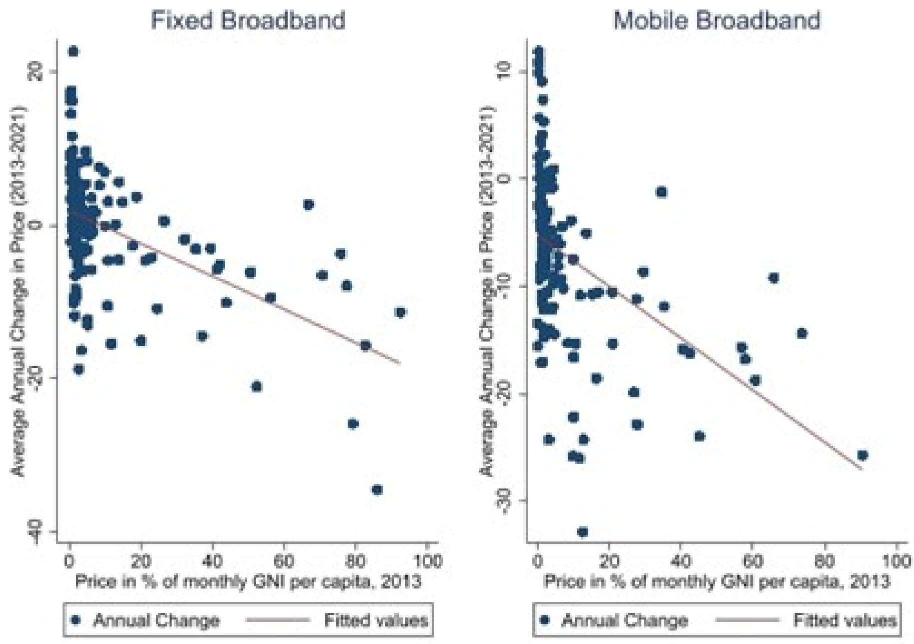
Telecom markets host a variety of packages with different levels of usage allowance and attributes, and this can make the measurement of price challenging in this sector. Several approaches are considered in the literature to address this challenge. Studies like Nicolle et al. (2018) use a hedonic price model, whereby price is estimated as a function of the attributes of packages. As such, a focus can be set on the price of a particular attribute, for instance, data allowance or quality, and be used in the analysis. Such modeling requires comprehensive data on all packages offered by operators and the results can be dependent on the functional form of the model. Other studies like Genakos et al. (2018) rely on the price of a particular basket of usage. As part of this approach, baskets of usage are defined, and the price of the least expensive offer is tracked for each basket. In this paper, we use the basket approach which does not require the availability of comprehensive data on packages – a task that would have been challenging to complete for a study that involves more than 150 countries/markets.

Interestingly, the ITU has defined several baskets of broadband packages and tracked their price since 2008.[11] We focused on two baskets that are the most representative of recent trends in data usage: (i) a basket of fixed broadband packages enabling at least 5 Gigabytes of data usage per month; and (ii) a basket of mobile broadband packages enabling at least 2 Gigabytes of data usage per month.[12] Figure 3 below reports the trends in fixed and mobile broadband prices in our dataset, with a faster drop in prices in countries starting from a high level.

[11] https://www.itu.int/en/ITU-D/Statistics/Dashboards/Pages/IPB.aspx.

[12] Data from Telegeography suggests an average monthly data usage per capita in developing countries rising from 9 GB in 2017 to 23 GB in 2020 on fixed broadband; and from 1.4 GB in 2017 to 4.2 GB in 2020 on mobile broadband. Note that ITU's price basket has evolved over time to reflect growing data usage by the average consumer. Two changes occurred during the period we considered in this study: one in 2017 when the allowance of the fixed broadband basket increased from 1 GB to 5 GB, and the allowance of the mobile broadband basket increased from 1 GB to 1.5 GB; and in 2020 when the allowance of the mobile broadband basket increased to 2 GB.

Figure 3: **COUNTRY-LEVEL TRENDS IN PRICES**



Source: Authors. Countries with baseline prices equivalent to more than 100 percent of monthly Gross National Income (GNI) per capita have been dropped from the dataset.

3.2 Interest variables

The analysis focused on three variables of interest: international connectivity, competition, and regulation in the telecom sector.

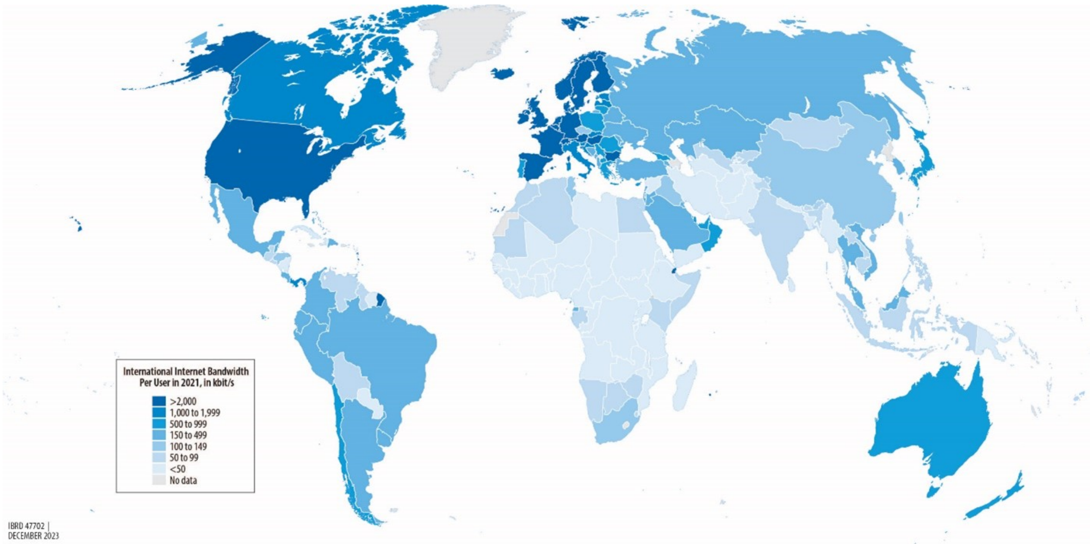
3.2.1 International connectivity

We considered the capacity of international digital connectivity measured by the international Internet bandwidth activated by Internet backbone providers, content providers, research and education networks, and enterprises in a country during a given year, SMC_band_{it}. Activated bandwidth differs from traffic which reflects the actual bandwidth usage by end-users. It also differs from the bandwidth of an SMC which reflects the capacity available for the group of countries it connects. As such, our focus is on the capacity of SMC available for a country, not the capacity of the SMC itself or the traffic generated by end-users.

The above approach applies to coastal countries. For landlocked countries, terrestrial cables are required to connect to SMCs. This means that the capacity of SMCs available for a landlocked country depends on the available cross-border terrestrial cables and the capacity of SMCs available in neighboring countries, especially those with a coastal area.

We collected data on international Internet bandwidth used by country and year from Telegeography, a proprietary but widely used industry database. Figure 4 presents the amount of international internet bandwidth per user in 2020, showing wide variation across countries.

Figure 4: **INTERNATIONAL INTERNET BANDWIDTH PER USER, 2020**



Source: Authors, based on data from Telegeography.

3.2.2 Competition intensity and regulatory framework

Competition intensity can be measured in various segments of the BB value chain. However, due to data constraints, the analysis focused on competition in the fixed and mobile BB retail markets which is correlated with competition intensity in upstream markets – like IP transit and international gateways. We measured competition intensity using the Hirschman-Herfindahl Index (HHI) of subscribers in the fixed or mobile BB market depending on the technology. Data on the HHI of the mobile broadband market came from the GSMA Intelligence database, a proprietary dataset, and considered all active mobile broadband network operators.[13] Data on the HHI of the fixed broadband market came from Telegeography and covered the 5 largest players, recognizing that fixed broadband markets often host a long tail of small retail operators focused on specific geographies or customer segments.

The regulatory framework is measured by the ITU's ICT Regulatory Tracker, a composite index of 50 indicators covering four dimensions, namely 'Regulatory Authority' (the functioning of the telecom sector regulator, its independence and autonomy in decision making), 'Regulatory Mandates' (the possible areas of intervention of the regulator), 'Regulatory Regime' (available types of regulations) and 'Competition Framework' (subjective assessment of compe-

[13] Virtual network operators are not included in the calculation.

tition intensity across market segments).[14] We used the aggregate score but also investigated the contribution of each regulatory sub-index and indicator in more detail.

3.3 Control variables

Control variables are grouped into two broad categories: variables related to the quality of connectivity and those related to the market size.

3.3.1 Quality and availability of connectivity

We measure the quality of connectivity by the amount of middle and last-mile infrastructure using the number of Internet exchange points (IXPs) which are crucial for the storage and processing of digital data across various networks. Availability of connectivity is measured by the following indicators:

- The number of fixed telephony subscriptions per inhabitant, reflecting the potential availability of fixed broadband which generally rely on or follow existing fixed telephony networks. That variable serves as a control when investigating the price of the fixed BB.

- Percentage of population covered by a mobile broadband network (3G or above).

3.3.2 Market size variables

Potential market size is proxied by several indicators, including:

- Population, expressed in logarithm.

- The average income per inhabitant, proxied by the logarithm of GDP per capita.

- Electricity access, proxied by the share of the population with access to electricity.

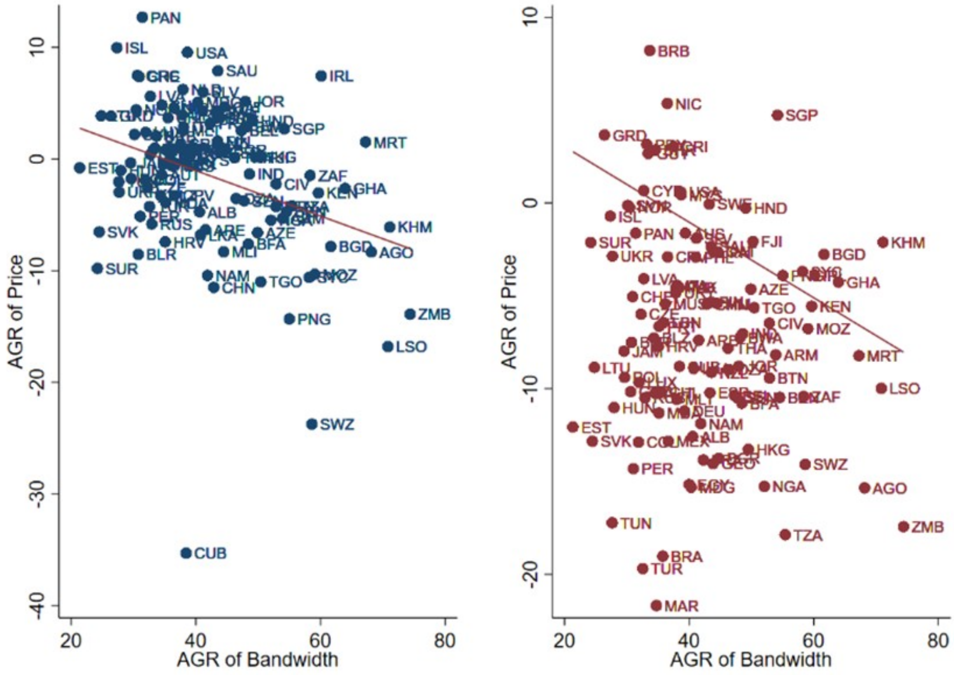
3.4 Descriptive statistics

A simple cross-country correlation between changes in international Internet bandwidth and Internet prices is plotted in Figure 5. It suggests that countries with a fast increase in submarine cable capacity experience a fast drop in both fixed and mobile broadband prices.

[14]See the Methodology note of the ICT regulatory tracker: https://app.gen5.digital/tracker/about.

Figure 5: **INTERNATIONAL CONNECTIVITY AND BROADBAND PRICE, 2013-2021**

Fixed broadband (left) Mobile broadband (right) prices



Source: ITU ICT Internet basket prices and Telegeography.

4 Estimation strategy

4.1 Reduced form econometric model

To estimate the impact of SMC on market outcomes, we relied on the following reduced-form equation which expresses the market outcome Y (*price*, *competition*) as a function of the capacity of international connectivity, the regulatory framework, and a set of control variables:

$$Y = f(SMC; X; Regul) \tag{1}$$

This leads to estimating the following general two-way fixed-effect (TWFE) econometric model:

$$Y_{i,t} = \alpha + \beta SMC_{i,t} + \gamma Regul_{i,t} + \delta X_{i,t} + \theta_t + \lambda_t + \epsilon_{i,t} \tag{2}$$

Subscripts i and t reflect country and year, respectively. θ_i is a country-fixed effect, which controls for geographical determinants of connectivity and other time-invariant unobserved country characteristics, and λ_t is a time-fixed effect, which allows controlling for changes in SMC technology and other unobserved common shocks, such as the COVID-19 pandemic or the 2008 financial crisis. $\epsilon_{i,t}$ is an error term. Driscoll-Kraay standard errors are computed, correcting for heteroscedasticity, contemporaneous spatial (cross-country) correlation, and autocorrelated disturbances.

4.2 Causal identification strategy

Our causal identification strategy rests on incidental changes in international connectivity due to the architecture of SMCs. Indeed, SMCs typically connect two or more countries following a particular route. The decision to follow a route is generally made by an international company (e.g., a global digital platform like Google or Meta/Facebook) or a consortium of telecom operators. As such, the route followed by an SMC is unrelated to the performance of a particular country. Further, countries along an SMC route can experience increased capacity of international connectivity although they do not host a landing station from the SMC. Such an indirect benefit results from terrestrial cross-border fiber optic cables that support a routing of traffic through a country that is connected with an SMC.

We also control for market supply and demand side factors in addition to country and year fixed effects to limit omitted variable bias. Indeed, the country-fixed effects control for unobserved supply and demand side factors that are country-specific, especially given that price is measured at the market level and not at the level of a particular operator. The year-fixed effects are assumed common across countries and are expected to capture any unobserved technological changes (e.g., transition from 2G to 3G or 4G; or transition from cooper to fiber).

5 Main results: Impact of international connectivity on Internet access price

Across estimations, the general reduced-form estimation framework set in equation (2) is calibrated to address the various research questions of this study. First, the analysis covers the impact of increased capacity of international connectivity on price at the global scale. Second, we highlight regional heterogeneity of the effects of international connectivity on fixed and mobile broadband prices.

5.1 General price effects of SMCs

We estimated the following two-way fixed effects (TWFE) model, using the international Internet bandwidth (in log) as the main variable of interest:

$$Y_{i,t} = \alpha + \beta \mathbf{CAP_{i,t}} + \gamma Regul_{i,t} + \delta X_{i,t} + \theta_t + \lambda_t + \epsilon_{i,t} \qquad (3)$$

Where $Y_{i,t}$ is the logarithm of fixed or mobile BB prices. $CAP_{i,t}$ denotes the capacity of international connectivity. We considered the dynamic or medium-term effects by introducing the lagged value of capacity into equation (3), i.e., CAP_{it-1}, CAP_{it-2} , CAP_{it-3}, CAP_{it-4} or CAP_{it-5}.

Results are reported in Tables 5 and 6 in the Appendix and summarized in Figure 6 below. They suggest that increased international connectivity capacity is associated with a drop in Internet prices: doubling the international bandwidth leads to up to 14% drop in fixed BB price, and up to 21% drop in the mobile BB price.

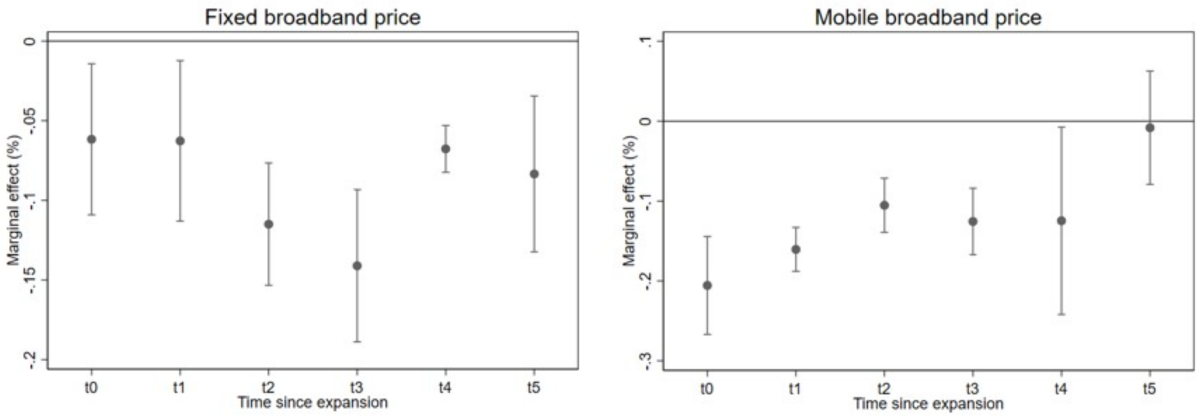
The evolution of these impacts differs by technology. The price effects of international connectivity amplify with time for fixed BB, and attenuate with time for mobile BB. Doubling the capacity of international connectivity in a given year generates an instantaneous drop in price of 6.2% for fixed BB and 21% for mobile BB. However, the impact on fixed broadband price increases to 14% 3 years post-expansion, before stabilizing around 7%-8% thereafter. On the contrary, the impact on mobile BB price drops to around 11%, 2 years post-expansion, and continues dropping towards a non-significant impact 5 years post-expansion.

These differences can be explained by two factors: the cost of last-mile connectivity which is crucial for the pass-through of wholesale cost savings, and the dynamic effects discussed in Section 2. Fixed BB networks provide dedicated Internet access to end-users, whereas mobile BB networks provide shared access to the Internet. As such, the cost of last-mile connectivity is higher for fixed BB Internet than for mobile BB Internet. It, therefore, takes more time for the wholesale cost savings to be passed on to end-users of fixed BB Internet than those of mobile BB Internet. Further, the reversal in impact – which starts early on for mobile BB and later for fixed BB – reflects quality improvement that is necessary in the medium term to keep up with the demand for connectivity.

Few additional findings can be derived from estimates of the coefficients of the control variables (Tables 5 and 6 in Appendix). The fixed broadband price is affected by access to electricity as well as by the availability and capacity of middle and last-mile digital infrastructure. In particular, fixed broadband price drops with the shares of the population with access to electricity or fixed telephony, but increases with the number of Internet exchange points, our measure of broadband network capacity, and a proxy for quality. We did not find any statistically significant impact of population size on the fixed broadband price. The coefficients of regulation and income are negative but not statistically significant.

For mobile BB Internet, its price drops with regulation, access to electricity, and availability of last mile network. We did not find any statistically significant effect of population size and network capacity on the price of mobile BB Internet. Income does have a statistically significant impact on the price of mobile BB Internet access.

Figure 6: **THE IMPACT OF INTERNATIONAL CONNECTIVITY EXPANSION ON BROADBAND PRICE**



Source: Authors

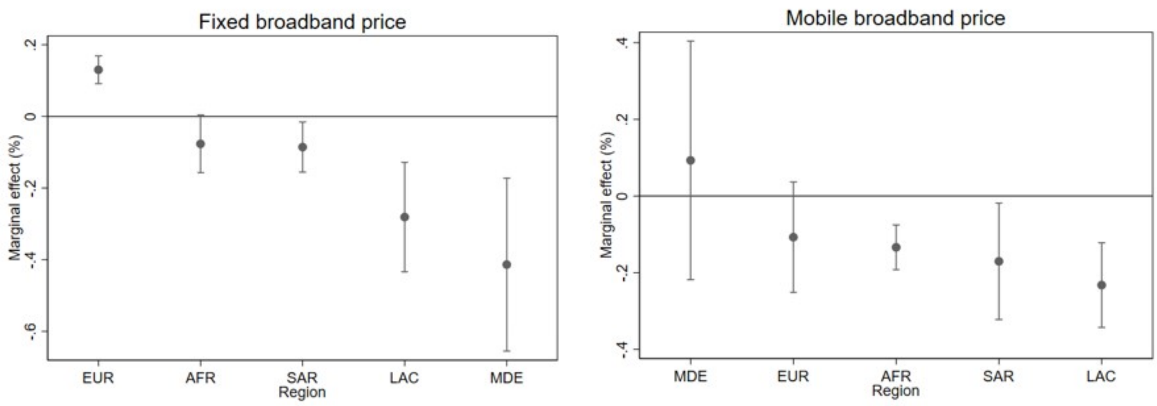
5.2 Regional effects

In a second step, possible regional heterogeneity in Internet price responses to SMC capacity was investigated. Equation (3) was estimated on a sample restricted to each region: Africa (AFR), Asia (SAR), Europe (EUR), Latin America (LAC), and the Middle East (MDE) – see Table 7 in the Appendix for the list of countries by region. The results are reported in Tables 8 and 9 in the Appendix and summarized in Figure 7 below, with a focus on the instantaneous effects – medium-term effects would come with less precision at the regional level due to reduced observations.

Except for Europe, the impact of international connectivity on fixed BB prices was negative and statistically significant. Fixed BB price drops with the expansion of international connectivity, especially in LAC and the MDE where the effects seem to be biggest with respectively 28% and 41% drop in fixed BB price for every doubling of international Internet bandwidth, followed by a 9% drop in Asia and 7% drop in Africa. In Europe, the instantaneous impact is positive and statistically significant but eventually drops with time with a negative and significant impact 5 years post-expansion – an 8% drop in fixed BB price for a doubling of international Internet bandwidth (See Figure 12 in Appendix).

For mobile BB price, the impact of international connectivity is not significant in the MDE or EUR, but is negative and significant in the other three regions: for every double of international connectivity capacity, mobile BB price drops by 23% in LAC, 17% in SAR and 13% in AFR.

Figure 7: **THE IMPACT OF INTERNATIONAL CONNECTIVITY EXPANSION ON BROADBAND PRICE – REGIONAL EFFECTS**



Source: Authors

6 The role of competition and regulation

6.1 Testing the competition channel

We tested the channel of the impacts of international connectivity on price by investigating its effects on competition intensity, measured by the degree of market concentration represented by the HHI. The estimated model is as follows:

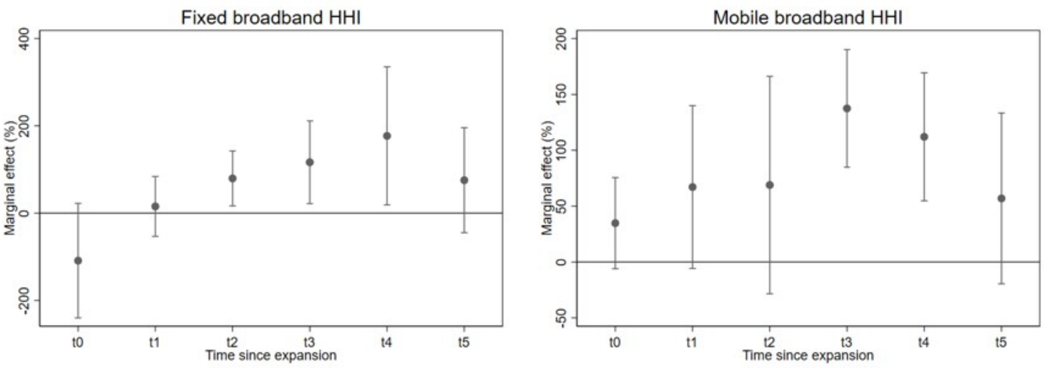
$$HHI_{i,t} = \alpha + \beta.\mathbf{CAP_{i,t}} + \gamma.Regul_{i,t} + \delta.X_{-i,t} + \theta_t + \lambda_t + \epsilon_{i,t} \tag{4}$$

Where $HHI_{i,t}$ is the Herfindahl-Hirschman Index of the mobile or fixed broadband sector in country i during year t. $X_{-i,t}$ is a set of controls like in $X_{i,t}$ except the measure of the availability of last-mile network which is not a determinant of market concentration. The other variables are the same in equation (3). The results are reported in Tables 10 and 11 in the Appendix and summarized in Figure 8 below.

It turned out that improved international connectivity is associated with increased market concentration in both the fixed and mobile broadband market segments. The impact takes time to materialize and evolves following an inverted-U shape: from no significant instantaneous impact to a positive and statistically significant impact 2 to 4 years post-expansion, and eventually to no impact 5 years post-expansion. For instance, doubling the capacity of international connectivity is predicted to increase market concentration by 177 points over 10,000, 4 years post-expansion, in the fixed BB segment, and by 137 points, 3 years post-expansion, in the mobile BB segment. The rise in market concentration can be explained by the trend in the ownership structure of new submarine cables. As suggested by Figure 13 in the Appendix, larger telecom operators tend to have a bigger stake in new SMCs.

These outcomes can be combined with the price effects presented in Figure 6 to infer the plausible channels of impact. For both fixed and mobile broadband, the results indicate that cost savings prevail as the main channel of impact in the short term – the first 2-3 years. Indeed, the price drop associated with increased international connectivity was sustained during that period, while market concentration was increasing. Beyond that period, the main channel of impact remains unclear, but the results suggest a mix of effects from increased competition and quality improvement as the impact on price tends to dwindle while the impact on market concentration subsides.

Figure 8: **THE IMPACT OF INTERNATIONAL CONNECTIVITY EXPANSION ON BROADBAND MARKET STRUCTURE**



Source: Authors

6.2 Heterogeneous effects of regulation

In this sub-section, we investigate whether the impact of SMCs on price and competition depends on the regulatory framework. In particular, our focus is set on those regulations that would (i) boost the price drop induced by international connectivity, or (ii) attenuate the rise in market concentration associated with international connectivity. This approach recognizes that some regulations may incentivize greater pass-through of wholesale cost savings or support open and non-discriminatory access to international connectivity, while others may have the reverse effects.

We test these hypotheses by estimating the below econometric model (5) which includes an interaction term between the change in each of the 50 regulatory indicators and international Internet bandwidth. Table 12 in the Appendix presents the list of regulatory indicators. We focus on regulatory change over the entire period covered by our sample (2008-2020 for fixed BB, and 2012-2020 for mobile BB), instead of the level, to identify how the impact of international connectivity varies across countries depending on the intensity of regulatory reforms over that period. This choice also reflects the discrete nature of the regulatory indicators – taking the values 0, 1, or 2 depending on the effectiveness of the target regulatory areas measured by the indicator.

Over the period covered by our dataset, we derived the average change in each regulatory indicator, denoted by $\bar{R}_i^j$, i.e., the average change in regulatory indicator j in the country i. This calculation was done for a set of relevant indicators for each type of broadband technology (fixed or mobile). For instance, regulation of radio spectrum does not apply to fixed BB; and likewise, licensing to Internet service providers does not apply to mobile BB.

We therefore estimate the following equation:

$$Y_{i,t} = \alpha + \beta.CAP_{i,t} * \bar{R}_i^j + \gamma.X_{-i,t} + \theta_t + \lambda_t + \epsilon_{i,t} \tag{5}$$

The variable $Y_{i,t}$ can be the price of fixed or mobile BB, or the HHI in the fixed or mobile market. Equation (5) was estimated at the time of the biggest impact, i.e., instantaneous effects on price, 3 years post-expansion for mobile BB and 4 years post-expansion for fixed BB. The results are reported in Tables 13 to 16 in the Appendix.

The independence of the regulator, its mandates, and its provision to enforce competition across segments of the broadband value chain are all crucial to boosting the impact of international connectivity on prices both for fixed and mobile BB. However, attenuating the impact of international connectivity on market concentration requires more regulatory changes beyond those that support price effects. Stronger independence of the regulator, control of market dominance, and infrastructure sharing – including spectrum – are additional regulatory reforms needed to lessen the impact of international connectivity on market concentration.

More specifically, the econometric estimates suggest the following regulatory boosters:

- **Fixed BB price:**competition in domestic and international fixed BB markets, including participation of foreign companies in these markets; autonomy in decision-making by the regulator in addition to public consultations before decisions and dispute resolution mechanisms; the regulator has a mandate on licensing and interconnection rates and price regulation.
- Status of the incumbent fixed line operator, license exemption, as well as the degree of accountability of the regulator and the implementation of local loop unbundling boost the impact of international connectivity on price, albeit with limited statistical precision.
- **Fixed BB HHI:** Consistent with the regulatory boosters identified for fixed BB price effects. However, these boosters are complemented by additional indicators on regulatory independence (funding diversity and a separate entity in charge of telecom regulation) and mandate, especially on quality of service, and criteria to regulate dominant operators.
- **Mobile BB price:** competition driven by the participation of foreign companies in the digital infrastructure market segment, mandated site colocation and sharing, allowing users to use voice over IP, as well as a regulatory mandate on interconnection rates and price, universal services, and consumer protection, in addition to dispute resolution mechanism and the availability of a national broadband plan.
- Competition in middle mile broadband infrastructure like leased lines, as well as a mandate on licensing also contribute to boosting the impact of international connectivity on mobile BB price, albeit with limited statistical precision.
- **Mobile BB HHI:** the boosters are consistent with those on price effects, in addition to regulation of dominant players, foreign participation in value-added services, regulatory mandate on spectrum and the ability to trade spectrum, mobile portability, and further independence of the regulator.

7 Robustness Checks

7.1 Potential endogeneity of SMC expansion

Despite the identification strategy presented above, the expansion of SMCs may still be endogenous as telecom operators in less competitive markets may purposely expand the capacity of international connectivity to reduce costs. To test the sensitivity of our estimates to such a potential reverse causality, we employed an instrumental variable approach.

Our identification strategy consists of taking parts of the variation in a country's total bandwidth that stem from changes in the bandwidth of countries they are connected to. For landlocked countries, we took the bandwidth of the coastal country hosting the closest SMC to their capital city. We have tested numerous definitions and measurements of such an instrumental variable and determined that being connected to a country in Sub-Saharan Africa throughout this study (2008-2020) is a strong determinant of changes in bandwidth in any other country in the world (see specification (1) in Table 17).

The findings presented in Table 17 lend support to our main results: increased SMC capacity is associated with a drop in broadband Internet price, for both fixed and mobile technologies.

7.2 Addressing the heterogenous and dynamic effects of SMC arrivals

The TWFE estimation strategy applied above faces two important inference challenges. The first challenge is related to the existence of possible heterogenous treatment effects which, if not considered, may be biased, and may even lead to produce estimates of opposite sign of the true Average Treatment on Treated (ATT). The second challenge is related to the existence of dynamic treatment effects, which reinforces the bias arising from the static framework, due to contamination effect of early treated groups on lately treated groups (De Chaisemartin and d'Haultfoeuille (2020); Baker et al. (2022); Liu et al. (2022)).[15] A third challenge is related to the nature of our baseline interest variable, the international bandwidth capacity, which is continuous and non-staggered, and therefore not appropriate for available Diff-in-Diff (DiD) frameworks designed to deal with the first two estimation challenges. We attempt to address these three challenges in the following sub-sections.

7.3 SMC arrival and BB prices

We replaced our interest variable, i.e., the international bandwidth capacity, with the cumulative number of SMCs that landed in a given country over the estimation period.[16] This

[15] In a TWFE setting, the treatment effect is a weighted sum of the average treatment effect on different treated groups g (early treated, later treated), at different points of time t. The weights for some groups are not related to the size of the group, which means that some groups are overweighed, and others are underweighted. More importantly, some weights may be negative, which may lead to type 1 and 2 errors, and this problem increases as the group has been treated for a long time, and many groups are treated in period t. Therefore, the problem stems mainly from the inclusion in the control group of units already treated as controls, which leads to the "forbidden comparison" (Goodman-Bacon (2021)).

[16] We prefer using the cumulative variation in the number of SMCs to the raw number SMCs, or the simple difference from one year to another. The raw number is a stock variable that takes many values, from 0 to 64 with very few observations or countries for high values the SMC number variable, which challenges the analysis by reducing the number of counterfactuals (switchers-in and- out) for these values. On the other hand, using a

variable consists in transforming the raw number of SMCs in (strictly increasing) cumulative difference, starting from 0 at the beginning of the estimation period to K at the end when the SMC number increased by K units over the estimation period. While this variable does not comprehensively reflect a country' international broadband capacity, it has the merit of better identifying the treatment since SMCs deployment in recipient countries is a critical source of increased international connectivity, and since this variable is of staggered and ordered nature.

Then, we address the issues of heterogenous and dynamic treatment effects by implementing the extended DiD estimator with multiple groups (DID_M), periods and non-binary treatments of de Chaisemartin and d'Haultfoeuille (De Chaisemartin and d'Haultfoeuille (2022); De Chaisemartin and d'Haultfoeuille (2023); de Chaisemartin et al. (2022)).[17] We then estimate the following model, considering the effect of the cumulative difference in SMCs (CD_{it}) on the logarithm of fixed or mobile broadband prices ($Y_{i,t}$), controlling for the lagged number of SMCs (SMC_L_{it}), and additional control variables (X'_{it}):

$$Y_{it} = \delta_0 + \delta_{\mathbf{1}}.\mathbf{CD_{it}} + \delta_{\mathbf{2}}.\mathbf{SMC\_L_{it}} + \delta_{\mathbf{3}}.\mathbf{X'_{it}} + \theta_i + \lambda_t + \epsilon_{i,t} \tag{6}$$

In addition to the baseline control variables (including the regulatory quality), we added the lagged number of SMCs to account for nonlinearities in the effect of SMC variation on BB price depending on their number, as there may be for instance return to scale in their deployment (cost-saving hypothesis).[18]

Last, since the mobile broadband price variable has a shorter time dimension, we had no option but to balance the sample between treated and untreated observation units by binning together the highest values of the variable, associated with few observations (using the *recat_treatment* option, as recommended by CDH), and to reduce the number of lags and placebos when using this price variable. We used a binning threshold of 15, based on the variable's treatment distribution represented on Figure 14 in the Appendix.

DID_M estimates of ($\hat{\delta}_1$) are reported in Figure 9 below and detailed in Tables 18 to 20 in the Appendix. Graph (A) on Figure 9 reports estimates using the fixed BB variable and points to a 1% significant negative and dynamic effect of SMC arrivals, starting one year after the treatment onset, persisting and intensifying afterward. However, these estimates point to

simple first-differenced, and therefore non-staggered, SMC variable would improperly reflect the staggered arrival of cables.

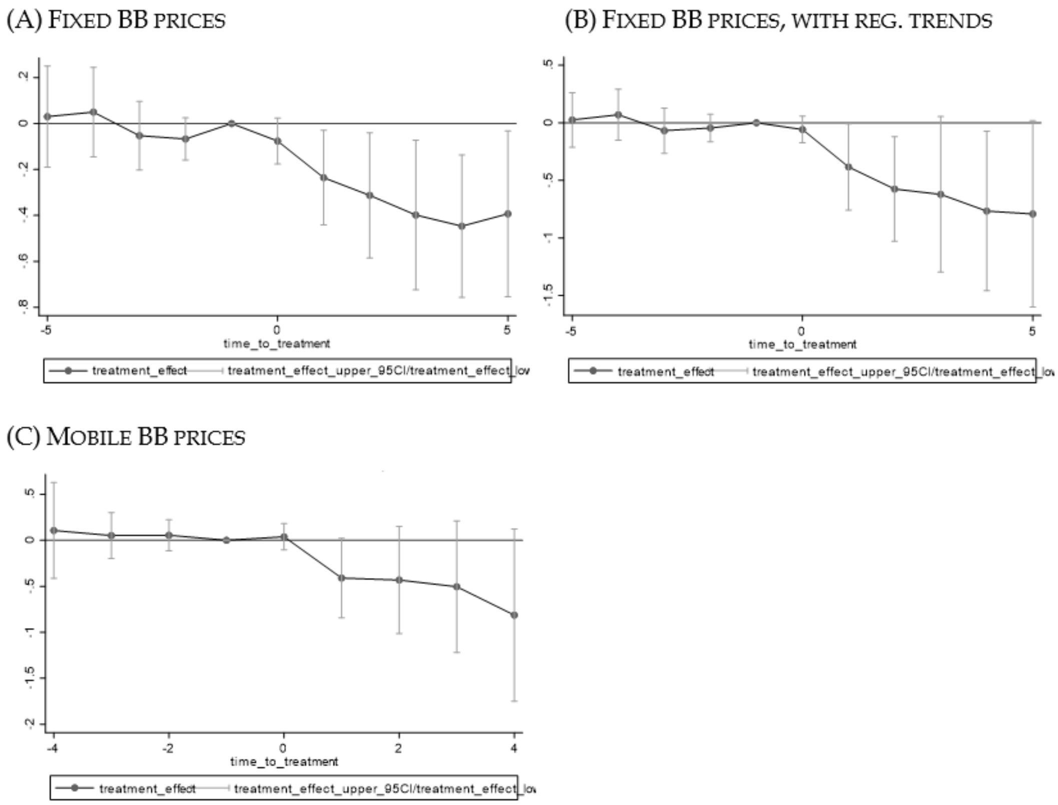
[17]Using the *did_multiplegt* Stata package. Other methodologies like Butts (2021) deal with spatial spillovers in difference-in-differences.

[18]We additionally control, in the following subsection, for market concentration to test the competition and regulation channels.

an eventual parallel trend violation, with a 10% significant pre-trend identified one year before the treatment occurrence. This pre-trend could be the result of specific regional trends in fixed BB prices, resulting from the unequal coverage of the last-mile fixed-line infrastructure prior to the treatment. To account for this possibility, we re-run estimation adding a non-parametric regional trend, consisting in comparing switching and non-switching countries belonging to the same region. Results, reported on panel (C) of Figure 9, show that the parallel trend hypothesis is respected, and confirms previous relationships. Moreover, controlling for these regional trends, results support a stronger effect of SMC rollout, with a 38% decrease in fixed BB price one year after the treatment, to 79% decrease five years later.

Regarding the impact of SMC on mobile BB prices, our results point to a same-magnitude but less significant effect on mobile BB prices. Estimates indicate, in a 10% confidence level, that mobile BB prices decrease by 41% one year after SMC arrival, and by 81% four years later. No violation of the parallel trend hypothesis is observed.

Figure 9: **Impact of SMCs on broadband prices: Staggered DiD estimates**



Source: Authors. Standard errors are clustered by country, robust to dynamic effects, and bootstrapped (200 replications).

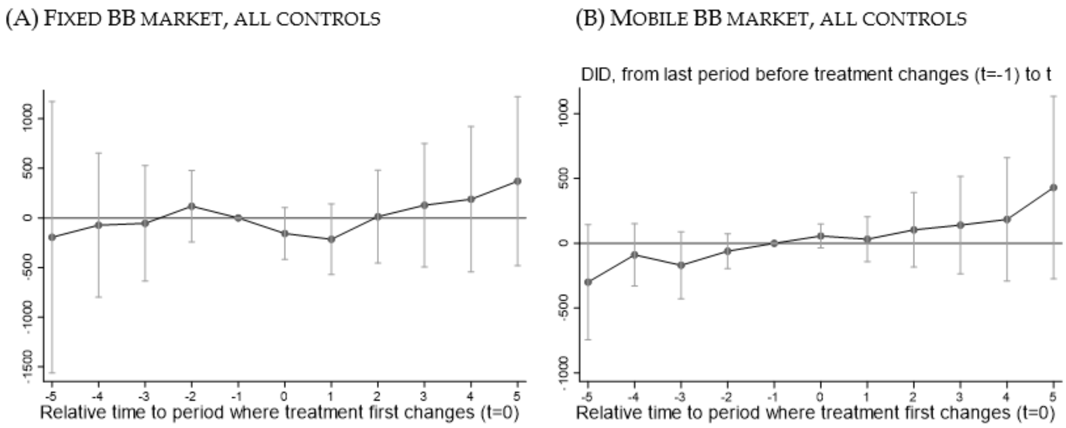
7.4 SMC arrival and market concentration

In the second step, we studied the impact of SMC arrival on competition intensity, measured by the concentration in fixed and mobile BB markets. We estimated the following model:

$$HHI_{i,t} = \mu_0 + \mu_{\mathbf{1}}.\mathbf{CD_{it}} + \mu_{\mathbf{2}}.\mathbf{X'_{it}} + \theta_i + \lambda_t + \epsilon_{i,t} \tag{7}$$

Where $HHI_{i,t}$ is the Herfindhal index in the BB markets. The model is estimated with baseline control variables set ($\mathbf{X'_{it}}$), and the SMC variable ($CD_{i,t}$)'s values are again binned above 15. DID_M estimates of ($\hat{\mu}_{\mathbf{1}}$) are reported in Figure 10 below and detailed in Tables 21 and 22 in the Appendix. No violation of the parallel trend hypothesis is observed. The estimates confirm the positive effect of SMCs on the concentration of fixed and mobile BB markets (panels A) and (B)), increasing over time, but not at the usual confidence level - estimates in the Appendix are significant at the 10% level.

Figure 10: **Impact of SMCs on market concentration: staggered DiD estimates**



Source: Authors. Standard errors are clustered by country, robust to dynamic effects, and bootstrapped (200 replications).

Overall, although the nature of the treatment emphasized in the section slightly differs from the initial focus of this study, the price impacts of the international bandwidth, analyzing the heterogenous and dynamic effects of the staggered arrival of SMCs on BB prices lead us to confirm our baseline results. Improvements in international connectivity have resulted in lower fixed and mobile broadband prices and are associated with a greater BB market concentration. The cost-saving effects of SMC infrastructure deployment therefore appear as a plausible channel for the reduction in Internet price observed.

8 Conclusion

This paper has sought to investigate how SMCs affect telecom market outcomes, especially the price of Internet access. Our analysis supports the hypothesis that the arrival of SMCs is associated with a drop in the price of fixed and mobile Internet access. These price effects decline with the available capacity of international connectivity and tend to dwindle over time, especially for mobile BB. They are more concentrated in developing countries, with no significant impact found in Europe or the Middle East regions. The African region has more limited SMCs capacity than other regions and also carries the smallest impact of SMCs on Internet access prices.

Our findings suggest that cost savings are the main drivers of the price effects in the short term, with some indicative role of competition and quality improvement in the medium term. They also suggest that regulation can be a powerful tool to increase the pass-through rate of cost savings and limit further concentration of retail broadband markets. In particular, an independent regulator, with a mandate to enforce competition through (i) reduced barriers to entry for domestic and foreign operators, (ii) shared infrastructure, including radio spectrum, (iii) regulation of interconnection and market dominance, as well as (iv) universal service provisions, and (v) consumer protection can contribute to boost the impact of SMCs on price and alleviate its effects on market concentration.

This study has focused on the impact of SMCs on nationwide Internet access prices. Future studies could explore the impact of SMCs on sub-national prices, especially those of fixed broadband Internet, as well as wholesale prices. Further, telecom regulation was deemed exogenous in this study. Future work could endogenize regulations and investigate the impact of SMCs on telecom regulatory reforms.

References

Akue-Kpakpo, A. (2013). Etude sur la connectivité internationale d'internet en afrique subsaharienne. *International Telecommunication Union.*

Baker, A. C., Larcker, D. F., and Wang, C. C. (2022). How much should we trust staggered difference-in-differences estimates? *Journal of Financial Economics*, 144(2):370–395.

Bates, P. (2014). Submarine cables in sub-saharan africa: terrestrial networks need to keep up. *Analysys Mason.*

Butts, K. (2021). Difference-in-differences estimation with spatial spillovers. *arXiv preprint arXiv:2105.03737.*

Cariolle, J. (2018). Telecommunication submarine-cable deployment and the digital divide in sub-saharan africa. *Available at SSRN 3202941.*

Cariolle, J. (2021). International connectivity and the digital divide in sub-saharan africa. *Information Economics and Policy*, 55:100901.

Cariolle, J. and da Piedade, C. (2023). Digital connectedness and exports upgrading: Is sub-saharan africa catching up? *The World Economy*, 46(11):3325–3344.

D'Andrea, A. and Limodio, N. (2019). High-speed internet, financial technology and banking in africa. *BAFFI CAREFIN Centre Research Paper*, 1(2019-124).

De Chaisemartin, C. and d'Haultfoeuille, X. (2022). Difference-in-differences estimators of intertemporal treatment effects. Technical report, National Bureau of Economic Research.

de Chaisemartin, C., d'Haultfoeuille, X., Pasquier, F., and Vazquez-Bare, G. (2022). Difference-in-differences estimators for treatments continuously distributed at every period. *arXiv preprint arXiv:2201.06898.*

De Chaisemartin, C. and d'Haultfoeuille, X. (2020). Two-way fixed effects estimators with heterogeneous treatment effects. *American Economic Review*, 110(9):2964–2996.

De Chaisemartin, C. and d'Haultfoeuille, X. (2023). Two-way fixed effects and differences-in-differences with heterogeneous treatment effects: A survey. *The Econometrics Journal*, 26(3):C1–C30.

Gallegos, D., Park, L. M., Morales Elorriaga, A., Fukui, R. F., Kelly, T. J. C., Ryu, J. M., and Gelvanovska-Garcia, N. (2020). Connecting africa through broadband: A strategy for doubling connectivity by 2021 and reaching universal access by 2030. *WBG Documents and Reports*.

Genakos, C., Valletti, T., and Verboven, F. (2018). Evaluating market consolidation in mobile communications. *Economic Policy*, 33(93):45–100.

Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics*, 225(2):254–277.

Hjort, J. and Poulsen, J. (2019). The arrival of fast internet and employment in africa. *American Economic Review*, 109(3):1032–1079.

Houngbonon, G. V., Mensah, J. T., and Traore, N. (2022). The impact of internet access on innovation and entrepreneurship in africa. *POLICY RESEARCH WORKING PAPERS*.

Imbruno, M., Cariolle, J., and De Melo, J. (2022). Digital connectivity and firm participation in foreign markets: An exporter-based bilateral analysis. *Available at SSRN 4169512*.

Liu, L., Wang, Y., and Xu, Y. (2022). A practical guide to counterfactual estimators for causal inference with time-series cross-sectional data. *American Journal of Political Science*.

Nicolle, A., Grzybowski, L., and Zulehner, C. (2018). Impact of competition, investment, and regulation on prices of mobile services: Evidence from france. *Economic Inquiry*, 56(2):1322–1345.

O'Connor, A. C. and Anderson, B. (2020). Economic impact of 2africa. *RTI International Working Paper 0214363.202.10*.

Schumann, R. and Kende, M. (2013). Lifting barriers to internet development in africa: suggestions for improving connectivity. *Analysys Mason Limited, London*, 9:30–5.

Simione, F. F. and Li, Y. (2021). *The macroeconomic impacts of digitalization in sub-saharan africa: Evidence from submarine cables*. International Monetary Fund.

Sterbenz, J. P., Hutchison, D., Çetinkaya, E. K., Jabbar, A., Rohrer, J. P., Schöller, M., and Smith, P. (2014). Redundancy, diversity, and connectivity to achieve multilevel network resilience, survivability, and disruption tolerance invited paper. *Telecommunication Systems*, 56(1):17–31.

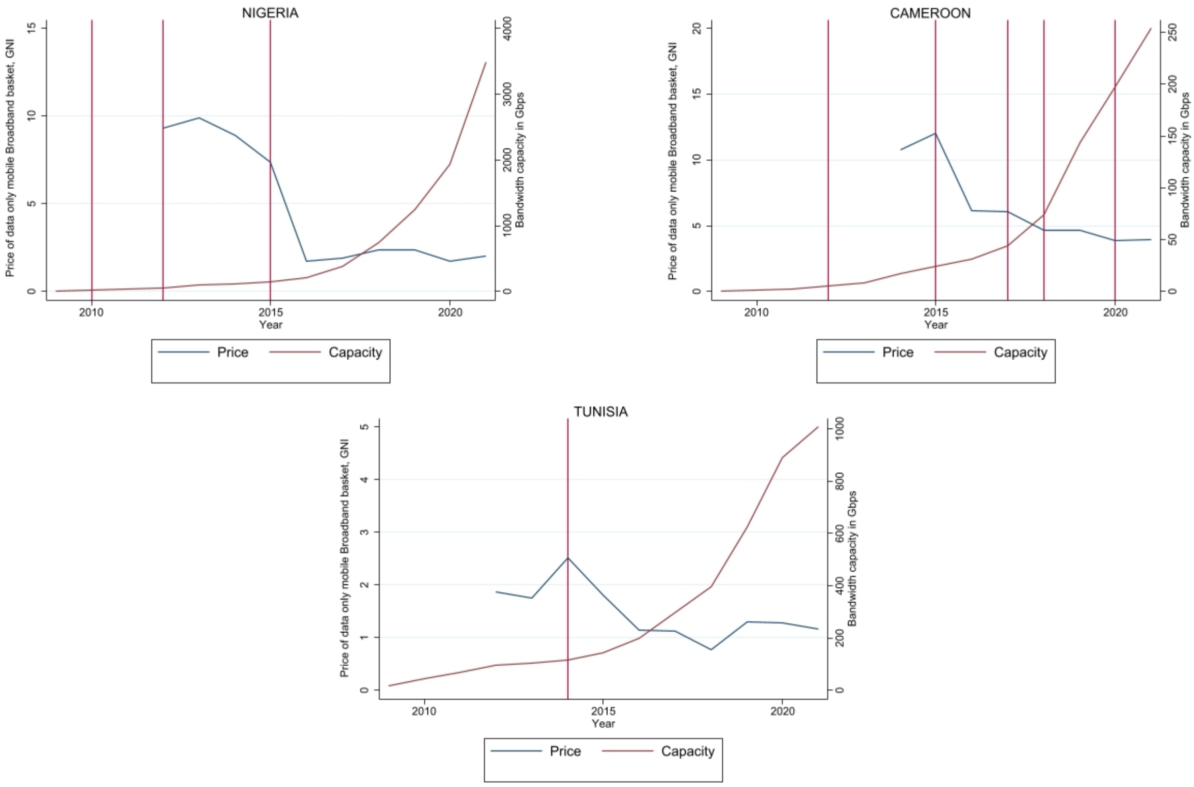
Weller, D. and Woodcock, B. (2013). Internet traffic exchange: Market developments and policy challenges. *Digital Economy Papers*.

Wentrup, R., Xu, X., Nakamura, H. R., and Ström, P. (2016). Crossing the digital desert in sub-saharan africa: Does policy matter? *Policy & Internet*, 8(3):248–269.

Appendix

A Mobile Broadband Price and the Arrival of SMCs

Figure 11: **Impact of Major Submarine Cable Arrivals on Internet Access Prices**



Source: Authors, based on data from Telegeography and ITU's ICT Price Basket.

B Data

Table 1: Sources and definition of the main variables

Variable	Source	Definition
Fixed_broadband_USD_log	ITU's ICT Price Basket	Price of the fixed broadband basket is the least expensive offer with a minimum monthly usage of 5 Gigabytes (GB) and an advertised download speed above 256 Kilobits per second (Kbps). Price is expressed in USD PPP and used in logarithm form.
Data_only_mobile_bdb_USD_log	ITU's ICT Price Basket	Price of data-only mobile broadband basket is the least expensive offer with a minimum monthly usage of 2 GB based on 3G or newer technologies. Price is expressed in USD PPP and used in logarithm form.
n_cables /n_cables_log	Telegeography	Number of Submarine cables laid in a given country.
Bandwidth / Bandwidth_log	Telegeography	International used Internet bandwidth corresponding to the inventory of capacity used by four categories of users: Internet backbone providers, content providers, research-educational networks, and enterprises and others. The capacity is measured in Gbps.
RegulationScore	ITU	ICT regulatory tracker is an index pinpointing the changes taking place in the ICT regulatory environment based on 4 sub-indexes (regulatory authority, regulatory mandate, regulatory regime, and competition framework) and 50 indicators.
HHI_fixedBdb / HHI_fixedBdb_log	Telegeography	Herfindahl-Hirschman Index (HHI) of the top 5 retail fixed-broadband operators.
HHI_mobileBdb / HHI_mobileBdb_log	GSMA Intelligence	Herfindahl-Hirschman Index (HHI) in the retail mobile broadband markets.
GDP_log	WDI	GDP in 2015 constant USD
GDPpC_log	WDI	GDP per capita in 2015 constant USD
Population_log	WDI	Total Population size, proxied by the size of the 15+ population.
Population_electricity	WDI	Share of population with electricity access
IXP	PCH	Number of Internet exchange points built in a given country.
Penetration_rate_FixedTel	ITU	Fixed-telephone subscriptions per 100 inhabitants.
Coverage_3G	ITU	Percentage of the population covered by at least a 3G mobile network.
nb_relation	Telegeography	The number of partner countries directly (first-order) reached by SMC.

Table 2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
	Fixed BB market analysis				
Fixed BB price (USD)	1,548	48.24835	128.082	0.06	1760.45
Fixed BB price (USD, log)	1,548	3.352292	0.8333747	0.0582689	7.473893
Cable #	1,548	5.564599	7.856278	0	64
Cable # (log)	1,548	1.45987	0.8675313	0	4.174387
Bandwidth (Kbps)	1,159	10428.04	44920.89	0.0870534	618921.8
Bandwidth (Kbps, log)	1,159	19.28478	3.183365	11.37428	27.15125
HHI fixed BB market	1,369	4919.819	2671.243	2000	10000
HHI fixed BB market (log)	1,369	8.360146	0.5273283	7.601402	9.210441
ICT Regul. Tracker	1,548	68.32805	19.689	2.5	99
GDP per cap (USD, log)	1,548	8.733258	1.3972	5.62835	12.11016
Population size (log)	1,548	15.9286	2.024634	9.291828	21.06751
Electricity access (% pop)	1,548	81.18987	27.48085	6	100
IXP #	1,548	3.531008	8.930874	0	126
Fixed-tel. subscript. #/100 inhab.	1,548	17.63871	18.03847	0	135.6037
1st-order connection #	1,440	17.54306	15.66487	0	62
% world GDP cabled	1,440	23.4261	24.5477	0	81.67836
Cable owner #	1,435	21.21882	19.64776	0	122
Internet disrupt. # [t;t-5]	941	1.167906	1.749611	0	11
Cable disrupt. # [t;t-5]	941	0.8150903	1.354985	0	10
	Mobile BB market analysis				
Variable	Obs	Mean	Std. Dev.	Min	Max
Mobile data-only price (USD)	864	15.06295	11.62074	0.48	149.92
Fixed BB price (USD, log)	864	2.561058	0.6738659	0.3920421	5.01675
Cable #	864	6.421296	8.549674	0	64
Cable # (log)	836	1.349159	1.008265	0	4.158883
Bandwidth (Kbps)	864	1.19E+10	4.66E+10	271040	6.19E+11
Bandwidth (Kbps, log)	864	19.77619	2.98788	12.51002	27.15125
HHI fixed BB market	864	4038.844	1354.842	1453	10000
HHI fixed BB market (log)	864	8.257281	0.2969905	7.282073	9.210441
ICT Regul. Tracker	864	73.7278	17.35198	2.5	99
GDP per cap (USD, log)	864	8.756964	1.41555	5.600855	11.27381
Population size (log)	864	16.15473	1.806391	11.407	21.06751
Electricity access (% pop)	864	82.24459	27.16472	7	100
IXP #	864	4.357639	10.66451	0	126
3G coverage (% pop)	864	83.29258	23.21129	0	100
1st-order connection #	781	19.72599	16.12338	0	62
% world GDP cabled	778	24.65296	21.08499	0	122
Cable owner #	781	25.70794	24.86616	0	81.67836
Internet disrupt. # [t;t-5]	529	1.514178	2.029211	0	11
Cable disrupt. # [t;t-5]	529	1.020794	1.548931	0	10

Table 3: Inoue-Solon Autocorrelation tests: Fixed Broadband

	H0: No auto-correlation of any order			
	IS-stat	p-value	N	Max T
Ha: Auto-correlation up to order 1	43.88	0	96	14
Ha: Auto-correlation up to order 2	54.09	0.001	96	14
Ha: Auto-correlation up to order 3	59.27	0.009	96	14
Ha: Auto-correlation up to order 4	67.26	0.022	96	14
Ha: Auto-correlation up to order 5	74.08	0.044	96	14
Ha: Auto-correlation up to order 6	80.34	0.069	96	14
Ha: Auto-correlation up to order 7	82.24	0.15	96	14
Ha: Auto-correlation up to order 8	84.21	0.243	96	14
Ha: Auto-correlation up to order 9	84.9	0.362	96	14

Table 4: Inoue-Solon Autocorrelation tests: Mobile Broadband

	H0: No auto-correlation of any order			
	IS-stat	p-value	N	Max T
Ha: Auto-correlation up to order 1	38.74	0	104	9
Ha: Auto-correlation up to order 2	60.09	0	104	9
Ha: Auto-correlation up to order 3	66.99	0	104	9
Ha: Auto-correlation up to order 4	68.83	0	104	9
Ha: Auto-correlation up to order 5	70.33	0	104	9
Ha: Auto-correlation up to order 6	72.59	0	104	9
Ha: Auto-correlation up to order 7	73.32	0	104	9
Ha: Auto-correlation up to order 8	73.32	0	104	9
Ha: Auto-correlation up to order 9	68.98	0	104	9

C Two-Way Fixed Effects Estimation Results

Table 5: International connectivity and fixed broadband price

	Year of expansion (1)	1 year post-expansion (2)	2 years post-expansion (3)	3 years post-expansion (4)	4 years post-expansion (5)	5 years post-expansion (6)
Bandwidth_log	**-0.062****	**-0.063****	**-0.115*****	**-0.141*****	**-0.068*****	**-0.083*****
	(0.021)	(0.022)	(0.016)	(0.02)	(0.006)	(0.018)
Regulatory index	-0.005	-0.003	-0.004	-0.003	-0.008***	-0.011**
	(0.003)	(0.003)	(0.003)	(0.004)	(0.001)	(0.003)
GDPpC_log	-0.069	-0.184	-0.354***	-0.380**	-0.452*	-0.247
	(0.127)	(0.107)	(0.065)	(0.104)	(0.21)	(0.196)
Population_log	0.752**	0.479	0.102	0.54	0.39	1.387*
	(0.291)	(0.354)	(0.443)	(0.492)	(0.796)	(0.618)
population_electricity	-0.025***	-0.024***	-0.019***	-0.022***	-0.025***	-0.01
	(0.002)	(0.002)	(0.004)	(0.003)	(0.005)	(0.007)
IXP	0.014***	0.015***	0.014***	0.010***	0.007*	-0.002
	(0.001)	(0.002)	(0.003)	(0.002)	(0.003)	(0.005)
Fixed tel. pen.	-0.011***	-0.009***	-0.008***	-0.007***	-0.003	-0.006
	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.003)
Constant	0	0	0	0	4.888	0
	(0.00)	(0.00)	(0.00)	(0.00)	(14.533)	(0.00)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,318	1,201	1,083	939	796	650
Number of countries	148	148	148	147	147	147

Table 6: International connectivity and mobile broadband price

	Year of expansion (1)	1 year post-expansion (2)	2 years post-expansion (3)	3 years post-expansion (4)	4 years post-expansion (5)	5 years post-expansion (6)
Bandwidth_log	**-0.206*****	**-0.160*****	**-0.105*****	**-0.126*****	**-0.125****	**-0.008**
	(0.026)	(0.012)	(0.014)	(0.017)	(0.046)	(0.026)
Regulatory index	-0.006***	-0.006***	-0.007***	-0.005***	-0.003**	0
	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)
GDPpC_log	0.710***	0.662**	0.603**	0.554*	0.16	-0.169
	(0.195)	(0.194)	(0.199)	(0.265)	(0.308)	(0.398)
Population_log	-0.622	-0.78	-1.019	-1.797**	-2.559***	-2.476*
	(0.41)	(0.514)	(0.62)	(0.526)	(0.589)	(0.917)
population_electricity	-0.022***	-0.021***	-0.022***	-0.019***	-0.021**	-0.034***
	(0.003)	(0.002)	(0.003)	(0.004)	(0.006)	(0.007)
IXP	0.004	0.003	0.002	0.004	0.000	-0.001
	(0.002)	(0.002)	(0.002)	(0.003)	(0.004)	(0.01)
Coverage_3G	-0.008***	-0.008***	-0.009***	-0.007***	-0.007***	-0.009**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Constant	0	0	0	31.425**	0	0
	(0.00)	(0.00)	(0.00)	(9.998)	(0.00)	(0.00)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	989	989	989	908	778	638
Number of countries	147	147	147	147	147	146

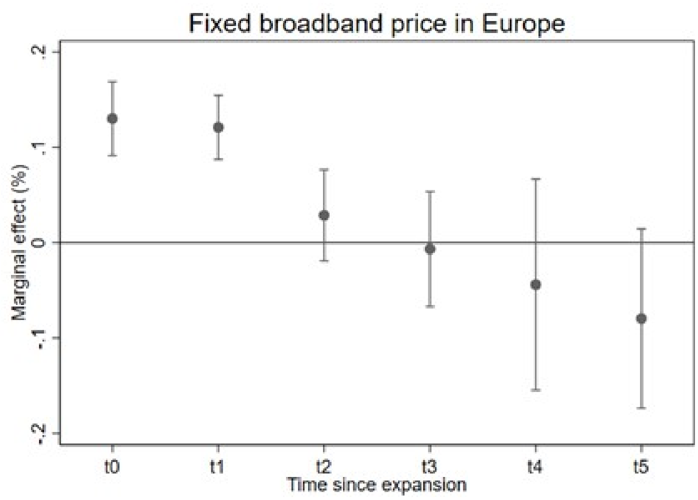
Table 7: List of countries by region

Africa		Asia	Europe		Latin America		Middle East
Algeria	Libya	Armenia	Albania	Moldova	Antigua and Barbuda	Peru	Afghanistan
Angola	Madagascar	Azerbaijan	Andorra	Monaco	Argentina	Puerto Rico	Bahrain
Benin	Malawi	Bangladesh	Austria	Netherlands	Aruba	St Kitts and Nevis	Iraq
Botswana	Mali	Bhutan	Belarus	North Macedonia	Bahamas, The	St Lucia	Israel
Burkina Faso	Mauritania	Cambodia	Belgium	Norway	Barbados	St Vincent and the Grenadines	Jordan
Burundi	Mauritius	China	Bulgaria	Poland	Belize	Suriname	Kuwait
Cabo Verde	Morocco	Georgia	Croatia	Portugal	Brazil	Trinidad and Tobago	Lebanon
Cameroon	Mozambique	Hong Kong SAR, China	Cyprus	Russian Federation	Cayman Islands	Uruguay	Oman
Central African Republic	Namibia	India	Czechia	San Marino	Chile	Venezuela, RB	Qatar
Chad	Niger	Indonesia	Denmark	Slovak Republic	Colombia		Saudi Arabia
Comoros	Nigeria	Japan	Estonia	Slovenia	Costa Rica		Türkiye
Congo, Rep.	Rwanda	Kazakhstan	Finland	Spain	Cuba		United Arab Emirates
Côte d'Ivoire	São Tomé and Príncipe	Kyrgyz Republic	France	Sweden	Dominica		
Djibouti	Senegal	Malaysia	Germany	Switzerland	Ecuador		
Egypt, Arab Rep.	Seychelles	Maldives	Greece	Ukraine	El Salvador		
Equatorial Guinea	Sierra Leone	Mongolia	Greenland	United Kingdom	Grenada		
Eritrea	Somalia	Myanmar	Hungary		Guatemala		
Eswatini	South Africa	Pakistan	Iceland		Guyana		
Gabon	Sudan	Philippines	Ireland		Haiti		
Gambia, The	Tanzania	Singapore	Italy		Honduras		
Ghana	Togo	Sri Lanka	Latvia		Jamaica		
Guinea	Tunisia	Tajikistan	Liechtenstein		Mexico		
Guinea-Bissau	Uganda	Thailand	Lithuania		Nicaragua		
Kenya	Zambia	Turkmenistan	Luxembourg		Panama		
Lesotho	Zimbabwe	Uzbekistan	Malta		Paraguay		
Liberia							

Table 8: International connectivity and fixed broadband price: Regional heterogeneity

	Africa (AFR)	Asia (SAR)	Europe (EUR)	Latin America (LAC)	Middle East (MDE)
	(1)	(2)	(3)	(4)	(5)
Bandwidth_log	**-0.077***	**-0.086****	**0.130*****	**-0.281*****	**-0.414*****
	(0.036)	(0.031)	(0.017)	(0.068)	(0.107)
Regulatory index	0	-0.005	-0.010***	0.001	0.001
	(0.003)	(0.004)	(0.002)	(0.007)	(0.002)
GDPpC_log	-0.317	-1.695***	1.099***	0.136	-0.741***
	(0.235)	(0.28)	(0.183)	(0.309)	(0.185)
Population_log	1.335	1.105**	2.492***	6.180***	5.416***
	(1.071)	(0.425)	(0.126)	(1.685)	(0.897)
population_electricity	-0.027***	0.009**	-0.693**	0.036***	-0.025**
	(0.004)	(0.003)	(0.232)	(0.01)	(0.008)
IXP	-0.021	0.007	0.030*	-0.005	0.163***
	(0.016)	(0.011)	(0.016)	(0.01)	(0.044)
Fixed tel. pen.	0.043***	-0.018*	-0.008***	-0.033***	-0.011*
	(0.007)	(0.009)	(0.002)	(0.008)	(0.006)
Constant	0	-0.742	0	-92.154***	0
	(0.00)	(6.898)	(0.00)	(22.616)	(0.00)
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	395	206	330	218	110
Number of countries	49	23	33	24	12

Figure 12: The impact of SMCs on fixed broadband price in Europe



Source: Two-way fixed effects estimates

Table 9: International connectivity and mobile broadband price: Regional heterogeneity

	Africa (AFR)	Asia (SAR)	Europe (EUR)	Latin America (LAC)	Middle East (MDE)
	(1)	(2)	(3)	(4)	(5)
Bandwidth_log	**-0.134*****	**-0.170****	**-0.107**	**-0.232*****	**0.093**
	(0.025)	(0.064)	(0.061)	(0.047)	(0.132)
Regulatory index	0.033***	-0.012***	-0.009	-0.017**	-0.012***
	(0.003)	(0.003)	(0.006)	(0.006)	(0.002)
GDPpC_log	2.560***	-1.059**	1.379***	-0.66	-0.460*
	(0.311)	(0.316)	(0.076)	(0.568)	(0.236)
Population_log	-4.838***	-1.051	4.759***	-2.963**	0.254
	(0.579)	(1.04)	(0.594)	(1.008)	(0.258)
population_electricity	-0.016***	0.009	-1.312*	0.019	-0.023***
	(0.004)	(0.005)	(0.594)	(0.021)	(0.005)
IXP	0.163**	0.003	0.029***	-0.045***	-0.053
	(0.061)	(0.01)	(0.005)	(0.013)	(0.029)
Coverage_3G	-0.008***	-0.009*	-0.004	0	0.001
	(0.001)	(0.004)	(0.003)	(0.001)	(0.002)
Constant	0	0	0	59.425**	3.967
	(0.00)	(0.00)	(0.00)	(18.782)	(4.004)
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	293	161	247	157	88
Number of countries	48	23	33	24	12

Table 10: International connectivity and fixed broadband market concentration

	Year of expansion (1)	1 year post-expansion (2)	2 years post-expansion (3)	3 years post-expansion (4)	4 years post-expansion (5)	5 years post-expansion (6)
Bandwidth_log	**-108.769***	**15.399**	**79.574****	**116.586****	**177.010****	**75.462**
	(57.99)	(29.723)	(26.599)	(38.707)	(61.531)	(43.301)
Regulatory index	0.668	3.344	0.687	-2.679	-11.289***	-16.492***
	(4.036)	(3.277)	(3.401)	(3.907)	(1.765)	(1.891)
GDPpC_log	1,701.6***	1,211.9***	1,120.8***	949.8***	830.1**	696.5***
	(268.3)	(192)	(228.4)	(230.1)	(207.4)	(138)
Population_log	985.2*	405.6	382	-1,352.9**	-2,074.0***	-1,498.6*
	(449.393)	(391.922)	(942.334)	(423.762)	(288.47)	(600.402)
population_electricity	-35.6***	-40.536***	-43.715***	-31.002***	-25.618***	-30.514**
	(5.15)	(4.303)	(6.263)	(2.542)	(3.732)	(9.444)
IXP	8.069***	5.168	5.289	7.841	14.828**	21.807***
	(2.112)	(2.991)	(3.642)	(4.675)	(4.053)	(4.331)
Constant	-21,249.5**	-9,934.90	-9,565.00	0	30,030.8***	24,749.7**
	(7,966.50)	(6,218.10)	(15,399.40)	(0.00)	(4,219.10)	(8,880.70)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,277	1,153	1,027	900	772	644
Number of countries	131	131	131	131	131	131

Table 11: International connectivity and mobile broadband market concentration

	Year of expansion (1)	1 year post-expansion (2)	2 years post-expansion (3)	3 years post-expansion (4)	4 years post-expansion (5)	5 years post-expansion (6)
Bandwidth_log	**34.767***	**67.112***	**68.906**	**137.4*****	**112.046*****	**56.948**
	(18.044)	(31.575)	(41.152)	(21.51)	(22.293)	(27.526)
Regulatory index	-22.063***	-21.460***	-19.371***	-14.185***	-13.459***	-10.763***
	(2.119)	(2.378)	(2.507)	(1.07)	(1.715)	(2.003)
GDPpC_log	29.462	29.474	196.78	431.58***	439.688**	399.587
	(153.327)	(182.45)	(138.176)	(64.051)	(157.427)	(251.77)
Population_log	970.96***	986.83***	1,209.5***	794.27***	1,015.471***	1,423.8***
	(253.679)	(243.126)	(232.443)	(159.034)	(82.859)	(176.368)
population_electricity	2.029	-0.273	-2.810*	-3.901**	-2.105	-5.144
	(1.947)	(2.384)	(1.446)	(1.166)	(2.404)	(5.482)
IXP	11.120***	11.071***	10.293***	11.779***	14.207***	17.763***
	(0.904)	(1.158)	(1.565)	(1.849)	(2.475)	(2.668)
Constant	-11,106.3*	-11,861.6**	-16,835.3***	0	-17,096.6***	-22,209.2***
	(5,197.50)	(5,102.30)	(3,353.10)	(0.00)	(1,868.40)	(4,820.80)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,466	1,320	1,175	1,028	881	734
Number of countries	148	147	147	147	147	147

Figure 13: Telecom operators' size and participation in SMCs

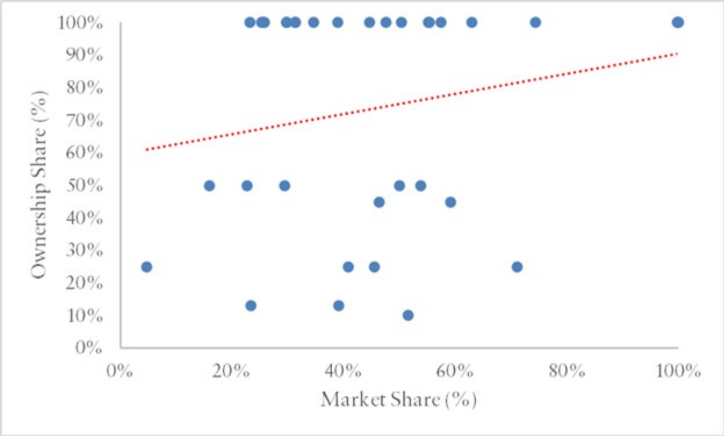


Table 12: Regulatory indicators and notations

Category	Regulatory items	notation
Regulatory authority	Separate telecom/ICT regulator	indepregu
	Autonomy in decision making	autonregu
	Accountability	accountregu
	Percentage of diversified funding	fundregu
	Public consultations mandatory before decisions	publiconsultregu
	Enforcement power	enforcregu
	Sanctions or penalties imposed by regulator	sanctionregu
	Dispute resolution mechanism	disputeregu
	Appeals to decisions	appealregu
	Existence of Competition authority	compauth
Regulatory mandate	Traditional mandate: entity in charge of quality of service obligations measures and service quality monitoring	qosmandat
	Traditional mandate: entity in charge of licensing	licensemandat
	Traditional mandate: entity in charge of interconnection rates and price regulation	intercomandat
	Spectrum: Entity in charge of radio frequency allocation and assignment	spectrummandat
	Entity in charge of Spectrum Monitoring and Enforcement	spectrummmandat
	Entity in charge of universal service/access	usmandate
	New mandate: entity in charge of broadcasting (radio and TV transmission)	not used
	New mandate: entity in charge of broadcasting content	not used
	New mandate: entity in charge of Internet content	not used
	New mandate: entity in charge of IT	not used
	Consumer issues: entity responsible for comparative tariff information, consumer education and handling consumer complaints	consumandat
Regulatory regime	Types of licences provided	licensetype
	License exempt	licensexempt
	Operators required to publish Reference Interconnection Offer (RIO)	publishoffer
	Interconnection prices made public	publishinterco
	Quality of service monitoring required	qosmonitored
	Infrastructure sharing for mobile operators permitted	sharedinframob
	Infrastructure sharing mandated	sharedinfra
	Co-location/site sharing mandated	sitecolo
	Unbundled access to the local loop required	llu
	Secondary trading allowed	tradespectrum
	Band migration allowed	refarming
	Number portability available to consumers and required from fixed-line operators	portafixed
	Number portability available to consumers and required from mobile operators	portamob
	Individual users allowed to use VoIP	usevoip
	National plan that involves broadband	nbbplan
Competition framework	Level of competition in local and long distance (domestic and international) fixed line services	compftel
	Level of competition in IMT (3G, 4G, etc.) services	compmbb
	Level of competition in cable modem, DSL, fixed wireless broadband	compfbb
	Level of competition in leased lines	compll
	Level of competition in International Gateways	compintl
	Status of the main fixed line operator	statusfno
	Legal concept of dominance or SMP	domconcept
	Criteria used in determining dominance or SMP	domcriteria
	Foreign participation/ownership in facilities-based operators	intlinfra
	Foreign participation/ownership in spectrum-based operators	intlmob
	Foreign participation/ownership in local service operators/long-distance service operators	intlfixed
	Foreign participation/ownership in international service operators	intlintl
	Foreign participation/ownership in Internet Service Providers (ISPs)	intlisp
	Foreign participation/ownership in value-added service providers	intlvas

Table 13: Marginal effects of international Internet bandwidth on fixed BB price depending on regulatory changes

compfbb	-0.591***	publishinterco	-0.084
	(0.139)		(0.049)
compintl	-0.929***	compftel	0.535
	(0.265)		(0.497)
intlfixed	-1.804***	domconcept	0.184
	(0.328)		(0.152)
intlintl	-1.199***	indepregu	0.135
	(0.081)		(0.495)
autonomdecis	-0.423***	compauth	0.139
	(0.099)		(0.091)
publiconsultregu	-0.467***	qosmandat	0.376
	(0.109)		(0.339)
disputeregu	-2.518***	usevoip	0.132
	(0.309)		(0.365)
intercomandat	-1.142***	nbbplan	0.008
	(0.105)		(0.04)
licensetype	-0.498***	sharedinfra	0.077
	(0.116)		(0.096)
statusfno	-0.647**	compll	0.381*
	(0.239)		(0.204)
licensexempt	-0.263**	qosmonitored	0.304*
	(0.114)		(0.137)
accountregu	-0.199*	intlisp	0.739***
	(0.094)		(0.138)
llu	-0.224*	intlvas	3.104***
	(0.112)		(0.287)
domcriteria	-0.028	sanctionregu	0.651***
	(0.042)		(0.126)
intlinfra	-0.005	appealregu	1.184***
	(0.183)		(0.124)
fundregu	-0.132	licensemandat	0.966***
	(0.134)		(0.155)
enforcregu	-0.213	usmandate	0.665***
	(0.491)		(0.116)
consumandat	-0.228	portafixed	0.755***
	(0.135)		(0.052)
publishoffer	-0.087		
	(0.161)		

Table 14: Marginal effects of international Internet bandwidth on fixed BB market HHI depending on regulatory changes

mdcompll	-2,553.520***	mdlicensexempt	268.51
	(454.466)		(535.046)
mdstatusfno	-4,683.371***	mdpublishoffer	584.819
	(369.718)		(461.689)
mddomcriteria	-1,607.645***	mdpublishinterco	577.637
	(364.601)		(902.724)
mdintlfixed	-7,594.240***	mdusmandate	1,453.92
	(498.405)		(888.824)
mdindepregu	-3,950.791***	mdusevoip	742.745
	(160.085)		(414.994)
mdfundregu	-1,265.808***	mdappealregu	502.454*
	(90.985)		(239.707)
mdqosmandat	-3,674.153***	mdcompftel	1,943.755*
	(230.407)		(823.362)
mdlicensemandat	-6,928.917***	autonomdecis	856.926**
	(590.889)		(228.818)
mdllu	-1,197.454***	mdportafixed	1,825.291**
	(159.672)		(556.212)
mdintercomandat	-2,682.721**	mdcompintl	1,624.519***
	(770.805)		(345.826)
mdaccountregu	-993.174**	mddomconcept	1,254.370***
	(328.654)		(231.482)
mdpubliconsultregu	-949.205*	mdintlinfra	4,237.862***
	(443.299)		(238.65)
mdcompfbb	-108.736	mdintlvas	5,635.521***
	(429.883)		(772.672)
mdintlisp	-569.795	mdenforcregu	3,188.078***
	(696.851)		(589.269)
mdintlintl	-978.814	mdconsumandat	1,613.735***
	(775.15)		(276.294)
mddisputeregu	-677.167	mdqosmonitored	2,583.714***
	(1089.921)		(151.888)
mdcompauth	-604.733	mdsharedinfra	2,843.829***
	(356.817)		(496.52)
mdsanctionregu	1,951.92	mdnbbplan	1,389.132***
	(1438.295)		(118.16)
mdlicensetype	819.046		
	(474.028)		

Table 15: Marginal effects of international Internet bandwidth on mobile BB price depending on regulatory changes

intlinfra	-3.758***	domcriteria	0.2
	(0.345)		(0.13)
disputeregu	-1.754***	enforcregu	1.181
	(0.329)		(0.628)
intercomandat	-1.456***	spectrummandat	0.386
	(0.391)		(0.826)
usmandate	-1.408***	refarming	0.174
	(0.233)		(0.163)
consumandat	-1.388***	accountregu	0.157*
	(0.181)		(0.069)
usevoip	-1.908***	spectrummmandat	0.525*
	(0.196)		(0.273)
nbbplan	-0.967***	autonomdecis	0.733**
	(0.069)		(0.261)
sitecolo	-0.719***	compintl	0.853***
	(0.136)		(0.149)
compll	-0.793**	intlisp	0.938***
	(0.243)		(0.137)
licensexempt	-0.602**	intlvas	0.622***
	(0.237)		(0.178)
licensemandat	-1.271*	fundregu	1.173***
	(0.569)		(0.266)
licensetype	-0.421*	sanctionregu	1.559***
	(0.189)		(0.259)
domconcept	-0.128	compauth	1.164***
	(0.279)		(0.178)
indepregu	-0.054	qosmandat	1.401***
	(0.476)		(0.242)
publiconsultregu	-0.261	publishinterco	1.285***
	(0.265)		(0.153)
appealregu	-0.14	qosmonitored	0.825***
	(0.286)		(0.104)
publishoffer	-0.066	compmbb	0.846***
	(0.104)		(0.119)
sharedinfra	-0.142	intlmob	2.987***
	(0.145)		(0.218)
sharedinframob	-0.012	tradespectrum	0.233***
	(0.08)		(0.056)
portamob	-0.283		
	(0.231)		

Table 16: Marginal effects of international Internet bandwidth on mobile BB market HHI depending on regulatory changes

mdcompll	-1,159.781***	mdusevoip	-137.198**
	(71.028)		(48.361)
mddomconcept	-536.010***	mdpubliconsultregu	-222.76
	(51.742)		(131.17)
mdintlinfra	-604.220***	mdappealregu	145.542
	(137.407)		(283.785)
mdintlvas	-1,868.272***	mdintlmob	528.058**
	(189.09)		(149.83)
mdindepregu	-2,668.718***	mdintlintl	307.483**
	(263.082)		(107.596)
mdaccountregu	-914.696***	mdlicensexempt	566.751**
	(119.442)		(178.535)
mdsanctionregu	-587.185***	mdcompintl	727.373***
	(127.487)		(83.073)
mddisputeregu	-1,192.888***	mddomcriteria	268.998***
	(82.936)		(57.166)
mdspectrummandat	-5,083.564***	mdautonomdecis	971.510***
	(426.575)		(155.373)
mdconsumandat	-1,370.985***	mdfundregu	638.913***
	(153.789)		(70.459)
mdlicensetype	-1,189.791***	mdenforcregu	1,749.899***
	(91.638)		(138.074)
mdportamob	-480.408***	mdlicensemandat	2,297.706***
	(64.719)		(323.036)
mdsharedinfra	-480.294***	mdintercomandat	1,796.413***
	(34.149)		(169.028)
mdtradespectrum	-586.303***	mdspectrummmandat	2,607.138***
	(40.245)		(215.515)
mdnbbplan	-415.832***	mdusmandate	1,662.983***
	(80.406)		(169.861)
mdcompauth	-423.377**	mdpublishinterco	1,153.714***
	(119.79)		(132.243)
mdqosmandat	-924.131**	mdsharedinframob	209.336***
	(289.713)		(26.304)
mdpublishoffer	-350.354**	mdsitecolo	390.456***
	(108.515)		(100.156)
mdqosmonitored	-232.442**	mdrefarming	590.489***
	(68.464)		(96.244)
		mdcompmbb	1,131.732***
			(57.274)

D Instrumental Variable Estimates

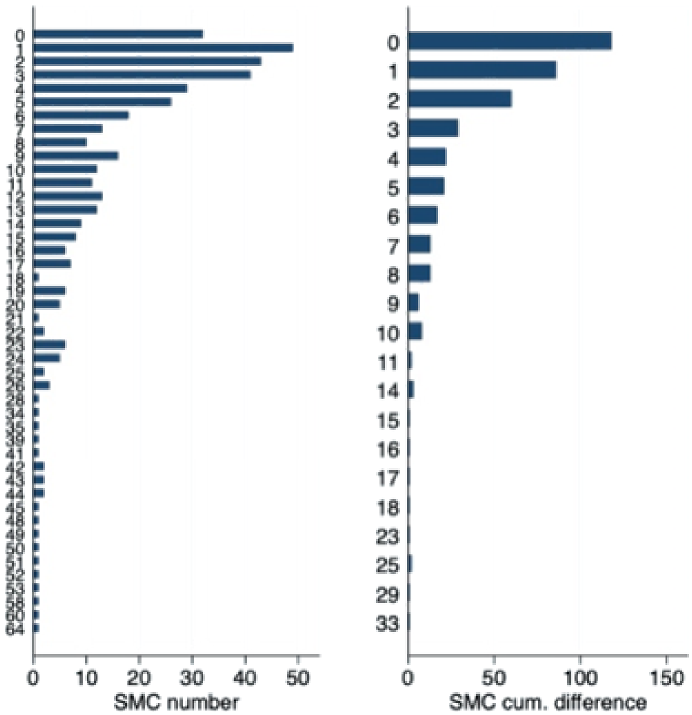
Table 17: First-stage and second-stage IV results

	(1)	(2)	(3)
	Log bandwidth	Log_FBB_price	Log_MBB_Price
Log BW_connected_countries	0.089***		
	(0.008)		
Log bandwidth		-0.536**	-1.201**
		(0.250)	(0.455)
Controls	Yes	Yes	Yes
Observations	1,161	1,267	957
AR F-stat		0.0298	0.000903
KP Wald F-stat		17.55	10.60
LM-weak		10.47	8.364

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

E DiD estimation with staggered, inter-temporal, and multi-groups treatment

Figure 14: Number of treated countries across values of SMC treatment variables, fixed BB sample



Note: using the baseline sample with fixed BB price variable, 1548 observations.

E.1 SMC arrival and BB prices, detailed staggered DiD estimates

Table 18: Dependent variable: Fixed BB price (log)

	$\hat{\delta}_1$ (Eq. (6))	SE	LB CI	UB CI	N	Switchers
Effect_0	-0.076598	0.0510601	-0.1766757	0.0234798	595	87
Effect_1	-0.2359241	0.1049975	-0.4417192	-0.0301291	494	84
Effect_2	-0.312826	0.1390746	-0.5854122	-0.0402399	401	80
Effect_3	-0.3982151	0.165979	-0.7235339	-0.0728964	308	75
Effect_4	-0.4467955	0.1580523	-0.7565781	-0.137013	269	73
Effect_5	-0.3930371	0.1837987	-0.7532825	-0.0327918	218	66
Placebo_1	-0.0672882	0.0467337	-0.1588862	0.0243098	470	60
Placebo_2	-0.053178	0.0762482	-0.2026245	0.0962685	302	48
Placebo_3	0.0496256	0.0992731	-0.1449497	0.2442009	178	24
Placebo_4	0.0298259	0.1123375	-0.1903555	0.2500073	83	18

Note: Standard errors were clustered by country, robust to dynamic effects, and bootstrapped (200 replications). Sample (1315 observations) covers up to 126 countries over 2009-2020.

Table 19: Dependent variable: Fixed BB price (log). With regional non-parametric trends

	$\hat{\delta}_1$ (Eq. (6))	SE	LB CI	UB CI	N	Switchers
Effect_0	-0.0584586	0.0590066	-0.1741116	0.0571944	595	87
Effect_1	-0.3835344	0.1911315	-0.7581521	-0.0089167	494	84
Effect_2	-0.5750701	0.2317062	-1.029214	-0.1209259	401	80
Effect_3	-0.6219049	0.3445298	-1.297183	0.0533735	308	75
Effect_4	-0.7666985	0.3530775	-1.45873	-0.0746666	269	73
Effect_5	-0.7915211	0.4129981	-1.600997	0.0179551	218	66
Placebo_1	-0.0453231	0.061217	-0.1653084	0.0746623	470	60
Placebo_2	-0.0684512	0.1003749	-0.2651861	0.1282836	302	48
Placebo_3	0.06959	0.1128454	-0.151587	0.290767	178	24
Placebo_4	0.0249611	0.1209993	-0.2121976	0.2621198	83	18

Note: Standard errors are clustered by country, robust to dynamic effects, and bootstrapped (200 replications). Sample (1315 observations) covers up to 126 countries over 2009-2020.

Table 20: Dependent variable: Mobile BB price (log)

	$\hat{\delta}_1$ (Eq. (6))	SE	LB CI	UB CI	N	Switchers
Effect_0	0.0386585	0.0726331	-0.1037024	0.1810194	318	36
Effect_1	-0.4104876	0.2204825	-0.8426334	0.0216581	248	33
Effect_2	-0.4318357	0.296242	-1.01247	0.1487986	183	28
Effect_3	-0.5046333	0.365068	-1.220167	0.2108999	104	22
Effect_4	-0.8134535	0.477762	-1.749867	0.1229601	92	22
Placebo_1	0.0548473	0.0859506	-0.1136159	0.2233104	236	21
Placebo_2	0.051269	0.1275094	-0.1986494	0.3011874	121	13
Placebo_3	0.1066206	0.2652556	-0.4132804	0.6265217	25	3

Note: Standard errors are clustered by country, robust to dynamic effects, and bootstrapped (200 replications). Sample (802 observations) covers up to 121 countries over 2013-2020.

E.2 SMC arrival and market structure, detailed staggered DiD estimates

Table 21: Dependent variable: Fixed BB market's HHI

	$\hat{\mu}_1$ (Eq. (7))	SE	LB CI	UB CI	N	Switchers
Effect_0	-157.2049	125.8189	-403.8099	89.40014	521	80
Effect_1	-215.2798	173.3022	-554.952	124.3925	453	80
Effect_2	12.64539	242.0587	-461.7897	487.0805	379	77
Effect_3	128.0447	317.4106	-494.0799	750.1694	292	72
Effect_4	188.3019	370.7242	-538.3174	914.9213	265	72
Effect_5	370.42	448.3701	-508.3853	1249.225	218	66
Placebo_1	117.6856	165.0637	-205.8393	441.2105	412	58
Placebo_2	-54.64949	290.0099	-623.069	513.77	282	42
Placebo_3	-73.00301	377.3501	-812.6093	666.6033	184	31
Placebo_4	-194.9506	638.0484	-1445.526	1055.624	86	13

Note: Standard errors are clustered by country, robust to dynamic effects, and bootstrapped (200 replications). Sample (1,010 observations) covers up to 112 countries over 2008-2020.

Table 22: Dependent variable: Mobile BB market's HHI

	$\hat{\mu}_1$ (Eq. (7))	SE	LB CI	UB CI	N	Switchers
Effect_0	56.38095	47.26526	-36.25895	149.0209	495	70
Effect_1	31.33538	87.98025	-141.1059	203.7767	386	62
Effect_2	103.8924	146.7287	-183.6957	391.4806	297	56
Effect_3	140.2361	191.5464	-235.1948	515.6671	198	48
Effect_4	184.4044	242.808	-291.4992	660.308	172	45
Effect_5	430.2074	358.9707	-273.3752	1133.79	125	34
Placebo_1	-60.61023	68.63356	-195.132	73.91155	371	47
Placebo_2	-169.6476	131.8776	-428.1276	88.83236	210	28
Placebo_3	-89.16347	122.5719	-329.4044	151.0775	95	14
Placebo_4	-299.914	226.456	-743.7678	143.9398	38	5

Note: Standard errors are clustered by country, robust to dynamic effects, and bootstrapped (200 replications). Sample (1,082 observations) covers up to 126 countries over 2009-2020.