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CABLES, SHARKS AND SERVERS:
TECHNOLOGY AND THE GEOGRAPHY OF THE FOREIGN EXCHANGE MARKET

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Cables, Sharks and Servers: Technology and the Geography of the Foreign Exchange Market
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ABSTRACT

We analyze the impact of technology on the production and trade in services, focusing on the location of foreign exchange transactions and the effect of submarine fiber-optic cable connections. Cable connections between local markets and major financial centers reduce the costs of trading currencies locally and increase the share of currency transactions taking place in the issuing country. But they also attenuate the effect of existing spatial frictions that prevent transactions from moving offshore to take advantage of agglomeration economies and thick-market advantages of major financial centers. In practice, this second effect dominates. Our estimates suggest that the advent of cable connections boosted the share in global turnover of London, the world's largest trading venue, by as much as one-third.

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I. INTRODUCTION

High-speed, low-cost communication is one of the distinguishing features of the 21st century world. What it implies for the geography of trade and production is unclear, however. It has been argued that ubiquitous communication encourages service-sector activities that benefit from agglomeration, spillovers and thick markets to concentrate in a handful of major centers and then for their products to be all but costlessly distributed to the rest of the world.[1] But cheap, high-speed communications also allow activities not benefiting from agglomeration to be spread more widely across the global economy, without significant sacrifice of managerial control, in response to rising costs in particular locations.[2] One can point to the City of London for finance and Silicon Valley for technology and innovation as examples of the former, and assembly operations and global value chains as instances of the latter.

In this paper we investigate these questions in the specific case of the global foreign exchange market. We ask whether advances in information and communications technology, specifically the advent of submarine fiber optic cables, led to a greater geographical dispersion or concentration of foreign exchange trading worldwide.

This is an appealing case for several reasons. First, the foreign exchange market is one of the largest financial markets in the world as measured by transactions, with an average daily turnover in the order of $6 trillion. Second, it is a market in financial services, as opposed to merchandise, which makes it relevant for thinking about the geographical distribution of activity in a post-industrial age. Third, the foreign exchange market has undergone a dramatic transformation since the late 1980s, reflecting the availability of cheap and efficient information and communications and the growth of electronic trading.

Investments in technology can affect the geographical distribution of economic activity, but changes in the geographical distribution of economic activity also provide an incentive for investments in technology. Examples of sharp, discontinuous, exogenous changes in information and communication technology would help to pin

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[1] For theoretical treatments see Krugman (2011) and Duranton and Puga (2004).

[2] As argued for example by Cairncross (1997).

down the causal effect, but technological progress tends to be continuous rather than discrete, endogenous rather than exogenous. Instances where it is possible to identify the diffusion of technology shocks over economic and geographical space are few and far between.

In the case of the foreign exchange market, we have just such a source of exogenous change and spatial variability. This is the laying of submarine cables starting in the late 1980s. Since different submarine fiber-optic cables came into use at different points in time, both the cross-section and time series dimensions enable us to identify the effects of technology on the location of foreign exchange transactions.

We regard the presence of a cable link between two countries as exogenous with respect to foreign exchange trading. Fiber-optic cables were laid for general telecommunication needs, not for purposes related to the foreign exchange market. They were laid by large telecommunication consortiums, not by financial institutions active in the foreign exchange market. Nonetheless, we also apply an instrumental variables strategy using the 3-dimension length of submarine fiber-optic cable routes.[3] We use these features of the natural environment to extract the exogenous component of whether and when countries were connected to the internet backbone.

A priori, the net effect on the geography of foreign exchange transactions is unclear. The reduction in transactions costs associated with greater ease of placing buy and sell orders on the large electronic platforms that exist only in the major financial centers of London, New York and Tokyo may encourage transactions previously completed onshore to move offshore to Britain, the U.S. and Japan. But fiber-optic connections may also increase the attractiveness of transacting through a local sales desk, insofar as that sales desk now has access to more timely information and a broader set of quotes, given that it can now communicate more easily with the major financial centers.

We find evidence of both effects in the data. On balance, however, we find that the advent of cable connections increased the share of foreign exchange transactions in

[3] This builds on work by Juhász and Steinwender (2018), who previously employed sea-floor topological irregularities arising from nature, such as domes, canyons and faults, as a source of variations that is exogenous to financial and economic activities.

the three major forex trading centers. This technology increased the share of offshore trading by 21 percentage points overall. It also had economically important implications for the distribution of foreign exchange transactions across financial centers, boosting the share of global turnover of London, the world's largest trading venue, by as much as a third.[4]

Our results also speak to the findings of earlier studies of the effects of broadband internet on the geography of international trade. Akerman et al. (2018), in a study of Norway, find that broadband internet increased the elasticity of trade in goods with respect to distance and economic size. Carluccio et al. (2018) find that the rollout of broadband in France corresponded to an increase in the value of goods imported by small and medium-sized firms, a class of producers that, they argue, are subject to significant information frictions.[5]

Section II takes up the question of whether the submarine fiber-optic cable network should be regarded as exogenous with respect to the foreign exchange market. Section III describes the data, Section IV some stylized facts, Section V our identification strategy. Section VI discusses our empirical framework and hypotheses. Section VII reviews the basic empirical results. Section VIII reports the IV estimates and Section IX various robustness checks. Section X gauges the distributional effects of cable connections across the world's financial centers, after which Section XI concludes.

II. EXOGENEITY

We treat the existence of a cable link between two countries as exogenous with respect to foreign exchange trading for reasons of geography, history, safety, market needs, and cost.

[4] The dampening effect of cable connections on the standard gravity trade determinants is robust to an instrumental variable strategy using the 3-dimension length of the cables in question, buttressing our causal interpretation.

[5] Using the international rollout of telegraph cables in the 19th century, Wache (2020) show that reductions in information frictions had a significant and positive impact on the bilateral international flow of financial capital from the UK.

Most fundamentally, the presence or absence of a submarine fiber-optic connection is influenced by seabed geography. Submarine cables can only connect terrestrial points with direct access to the ocean. Over half of the nodes of the fiber-optical cable network are on islands (Starosielski 2015). Singapore, which is a peninsula, has more cable connections (21) than mainland China (12), a much larger economy. Guam has as many cable connections (10) as Germany. Landing points are chosen in areas with gently sloping, sandy or silty sea-floors and without strong current to minimize risks of damage. That Iceland is surrounded by mid-ocean ridges explains, for instance, why three of the four cables it is connected to were only laid in the 2000s, late in our sample period.

History has also shaped the current fiber-optic network. Broadly speaking, the contours of the current network follow those of the telegraph network laid in the nineteen century and of the coaxial network laid in the 1950s through 1970s. Fiber-optic cables connecting New Zealand, for example, are located in almost exactly the same areas as telegraph cables laid in the late 19th and early 20th centuries. In part this reflects considerations of geography and current cited above. It reflects learning from this earlier experience: a history of system failures due to currents, interference from fishing vessels and natural disasters encourages modern cable companies to ply historical routes.[6]

Another factor in this persistence is geopolitics. Once a route is seen by the cable industry as secure, because it has been shown to be sheltered from man-made interference such as wars, sabotage, and terrorist attacks, there is a tendency to stick to it.[7]

Our reading of industry publications indicates that fiber-optic cables were not laid for reasons related to the foreign exchange market. Their underwriters foresaw them as efficient and profitable vehicles for carrying long-distance telegraphic

[6] Examples of natural disasters impacting the internet backbone are numerous, a recent famous one being Japan's tsunami in 2011, which also broke several fiber-optic cables.

[7] The early telegraph network of the nineteen century was mapped over colonial geographies for military reasons. For instance, several telegraph cables laid by the British Empire landed only on imperial territory for fear of interference by foreign powers. Telegraph cables between China and the UK were famously sabotaged during the Boxer rebellion of 1899-1901. That Guam hosts a U.S. military base partly explains why it has played a key role in the cable network.

communication, telephone calls and fax traffic, only a small portion of which, at best, was related to trading foreign exchange.[8] Press reports from the late 1980s and early 1990s highlight prospective increases in efficiency and capacity for telephony, fax and television transmission. An article published in the *New York Times* at the time of the inauguration of the first transatlantic fiber-optic cable stressed that it would "vastly increase the number of calls that can be placed to Europe at one time" and "will provide international telephone calls and data transmissions free of delay and distortion" (Sims, 1988).

Additional impetus for development of the submarine fiber-optic cable network in the 1990s came from development of the internet. To be sure, it was anticipated that the internet would be useful for a range of business applications, including some of interest to financial markets.[9] But financial applications were not the main motivation for building out the internet backbone in the 1990s and early 2000s.[10]

Finally, submarine fiber-optic cables are typically owned by large telecommunication consortiums, not by financial institutions. The SEA ME WE 4 cable connecting South East Asia, the Middle East and Western Europe is owned by 17 telecom companies from 17 different nations. These companies act as bandwidth dealers selling bandwidth to mobile phone companies and internet providers. Among the wide range of customers of the internet providers in question may be financial market participants, but these are typically dwarfed in importance by other customers – which means that investment in cables was undertaken principally with these other customers in mind.

[8] The majority of companies that laid telephone cables through the 1980s were government-owned or – affiliated monopolies. Most were telecommunication companies (see below and Table A2 in the online appendix for information on the owners of the cables connected with London, New York and Tokyo in 2002).

[9] For instance, an article in *The Economist* in 1994 foresaw that online services and information providers "includ[ing] stockbroking (through such firms as Bloomberg), financial information (Dow Jones), news services (Reuters) and databases (NEXIS/LEXIS)" would benefit from the development of an "information highway" capable of transmitting voice, text, video and data simultaneously.

[10] Nor have they been the motivation for more recent investments in submarine fiber-optics by Silicon Valley companies, like Google, which have invested in submarine fiber-optic cables (like those connecting Florida with Brazil and Southeast Asia with Japan). In 2010 Spread Networks unveiled an 827 miles terrestrial cable running through mountains and under rivers from Chicago (home to the Chicago Mercantile Exchange where derivatives are traded) to New Jersey (home of the Nasdaq data center). Hibernia Express, which was tested in September 2015, is the first submarine cable laid for the express purpose of electronic trading, which falls outside the sample period we consider.

Endogeneity might still enter through omitted variables that influence both the share of trading occurring offshore and cable access. For instance, financial deepening may create incentives to connect a country to the network of undersea cables, and also encourage financial innovations and investments in market infrastructure that buttress onshore trading. Insofar as this would dampen the estimated effect of cable connections on offshore trading, our estimates of the impact of cables would be biased downward (and should be regarded as a lower bound on the effect of cable connections). It might also be argued that the presence of a cable is endogenous because its existence is related to general telecommunication needs that are a function of population size, which in turn affects the level of financial market activity. However, our dependent variable, as we explain below, is the share of the domestic currency traded offshore, not domestic foreign exchange turnover (or the level of financial activity). This transformed measure varies widely across countries with similar levels of financial depth. For instance, the shares of US dollar and sterling transactions taking place offshore stood at about 80 per cent and 40 per cent respectively, in 2013; yet both currencies are issued by nations with the largest and most liquid foreign exchange markets globally. Be this as it may, instrumental variables estimates confirm our central findings.

III. DATA

We take data on the network of submarine fiber-optic cables from TeleGeography's interactive Submarine Cable Map.[11] These data were collected by Global Bandwidth Research, a consultancy specializing in data and analysis of long-distance networks and the submarine cable market. They provide information on 368 submarine cables starting in 1989. The information includes the cable's profile, name, year when it was ready for service, length, owners, and geographical coordinates of its landing points.

For data on the location of foreign exchange trading, we obtained confidential estimates of onshore, offshore and global foreign exchange turnover by currency from the Bank for International Settlements (BIS). We have data for 55 currencies (including

[11] TeleGeography has made the source code behind the interactive Submarine Cable Map available for download at https://github.com/telegeography/www.submarinecablemap.com.

12 euro legacy currencies) in seven years (1995, 1998, 2001, 2004, 2007, 2010 and 2013). The data were collected in the context of the BIS's triennial central bank surveys of foreign exchange and derivatives market activity.[12] The number of currencies and trading locations covered by the BIS surveys has increased over time. Our baseline results utilize the full data set, but we also analyze a balanced panel in robustness checks.

BIS statisticians define foreign exchange turnover as the daily average of the notional amount (in US dollar equivalents) of all transactions struck in April of the year of the triennial survey.[13] They produce data in "net-net" terms. In other words, they adjust for local double-counting – i.e. for transactions between reporting dealers located in the same country – as well as for cross-border double-counting.[14]

Foreign exchange turnover is allocated across countries according to where the transaction is arranged. Since 2004, BIS statisticians have specified that they mean the location of the initiating sales desk (which may not coincide with the location of the

[12] These surveys offer the most comprehensive and internationally consistent information on the size and structure of the foreign exchange market although, as King and Mallo (2010, p. 71) observe, "the underlying data remain largely unexplored." An exception is e.g. He et al. (2015), who do not however focus on the impact of technology on the location of FX transactions, as here. The exact location of offshore transactions is not known, but an overwhelming share can be shown to take place in major financial centers such as London, New York or Tokyo (see below). Whether or not triannual data are too coarse or infrequent to allow us to identify the impact of the establishment of a cable connection on the location of activity is an empirical question. Our empirical results suggest that they have significant information content. Note that we are not studying the impact of a cable connection on, inter alia, daily movements in asset prices, for which higher frequency data would be desirable. In practice, moving trading activity offshore requires establishing a business relationship with a foreign partner. It requires reorganizing one's business practice. It takes time. For instance, relocation of UK-based banking activities by international banks is still ongoing several years after the Brexit referendum. All this suggests that triannual data are informative.

[13] A broad array of foreign exchange instruments are covered, including spot transactions, outright forwards, foreign exchange swaps, currency swaps, currency options and other foreign exchange products, including nondeliverable forwards. Dealers report their transactions in these instruments with other reporting dealers, other financial institutions and non-financial customers. Each transaction is recorded once, and offsetting contracts are not netted. There is no distinction between sales and purchases. Direct cross-currency transactions (e.g. pound sterling for Swiss francs) are counted as single transactions. Transactions that use a vehicle currency (e.g. the US dollar) are counted as two separate transactions. See King and Mallo (2010) for further details. The data include transactions in dark pools such as MidFX and BGC.

[14] For instance, local inter-dealer transactions in Germany are halved to obtain the correct turnover for Germany. As another example, transactions between a reporting dealer located in the United Kingdom and a reporting dealer located in France are halved to obtain the correct estimate of global turnover.

trading desk).[15] For example, when an employee of a savings bank in Berlin asks his or her foreign exchange dealer at Deutsche Bank Frankfurt to buy Y50 million against euros, this transaction will be recorded as having taken place in Germany, because the sales desk is in Germany. Actual trading could take place elsewhere, for example by traders at Deutsche Bank London.[16] BIS statisticians use the trading desk to determine the location of a deal when no sales desk is involved.[17] Discussions with foreign exchange dealers suggest that banks net and aggregate their positions in the same location (in the back-office) where they trade (in the front-office). In other words, there are no major differences between sales and trading desks in most cases.[18] The distinction might still be more important in the case of smaller financial centers where the sales desk might remain local but the trading desk might be in a larger center, such as London, New York or Tokyo. But readers should note that when a bank decides to relocate its trading desk to a major financial center, it may move its sales team there, too.

IV. STYLIZED FACTS

Since the mid-1990s, transactions in foreign exchange have increasingly taken place offshore, in locations other than the country issuing one of the currencies involved in the trade.[19] The global weighted average rose by five percentage points between 1995 and 2013, to about 78%.[20] Insofar as this estimate is considerably higher than the

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[15] The nationality of the reporting dealer is not relevant in this context. For example, when UBS Frankfurt reports trades to the Bundesbank, these transactions are allocated to Germany.

[16] In reality the dealer will not execute every single trade individually because transaction costs would be excessive and he/she would take credit risk for each transaction. Dealers will instead add additional trading orders to their dealing books, net FX positions internally (via Autobahn, BARX or Velocity, for example) and trade the residual either on exchange platforms (EBS, Reuters, etc.) or via OTC transactions. From a BIS perspective, what matters is the location where the FX book is aggregated and netted (i.e. at the back-office).

[17] Given the growing use of electronic execution methods, moreover, in the BIS Triennial Survey conducted in April 2016 the sales contact of the electronic platform who services the client, or the trading desk or the electronic matching engine, was used to determine the location of a deal when no sales desk is involved (see BIS 2015).

[18] This is consistent with the observation that there were no major breaks in the data when the BIS changed its definition of trading location in 2004 from the trading desk to the sales desk.

[19] See Figure A1 in the online appendix.

[20] The weighted average is the sum of foreign exchange trading occurring offshore in all currencies scaled by the sum of total (onshore and offshore) foreign exchange trading in all currencies. The unweighted average is the arithmetic average of the individual currency shares traded offshore.

lower bound of 50% (one of the two currencies involved in a foreign exchange trade undertaken in a particular national market is the currency of a foreign country, meaning that it is necessarily traded offshore), this confirms that a substantial fraction of transactions occur in third markets.

From 1995 to 2013 the global unweighted average of the individual currency shares of foreign exchange trading occurring offshore essentially tripled, from 20 to 60 per cent. (The unweighted arithmetic average is not subject to the 50% lower bound.) This suggests that internationalization (trading in third markets) affected not just major currencies like the US dollar but also other units. Offshore trading increased markedly between 1997 and 2004 (when all countries in our sample were connected to the internet backbone), and continued to rise thereafter. This makes it important to include time fixed-effects in our regressions to control for global developments that might drive the share of foreign exchange trading occurring offshore, such as the rise of high-frequency trading, co-location services or regulatory changes.

Not only does a substantial fraction of offshore transactions occur in markets such as London, New York or Tokyo, but that share is increasing.[21] There is, however, considerable heterogeneity among currencies in the extent of foreign exchange trading offshore. Note in Figure 1, which focuses on a selection of units, the relatively high shares of the US dollar and also the euro and Japanese yen, compared to the relatively low shares of several emerging market currencies, like the Korean won and Indian rupee, while still other emerging market units have high shares (for example the Polish zloty). In total, only 9 of the 55 units had an offshore share of less than 50%. In other words, most currencies actively trade offshore.

V. IDENTIFICATION

[21] This is evident from Figure A2, which shows the evolution between 1995 and 2013 of scaled and unscaled Herfindahl indices of concentration of global foreign exchange transactions occurring offshore in these three financial centers (left-hand-side panel), as well as the combined share of global transactions they account for (right-hand side panel). Both charts show a clear upward trend, testifying to the importance of London, New York and Tokyo in the global market for offshore foreign exchange transactions.

Our identification strategy builds on the special role of the UK, the US and Japan in electronic foreign exchange trading. It is in these countries that matching servers of EBS and/or Thomson Reuters – the leading platforms for electronic broking and trading – are located. EBS servers have been located in the UK, US and Japan since 1990. Thomson Reuters has servers in both the United Kingdom and the United States.[22]

A direct or indirect connection to the UK, US or Japan via a submarine fiber-optic cable increases bandwidth. It reduces the costs of undertaking transactions electronically through EBS and/or Thomson Reuters, rather than by other means or in other venues. Greater bandwidth helps to relax barriers to information flows, data processing, and matching buy and sell orders. This is also attractive to traders using other internet-based applications, such as e.g. Bloomberg, Haver Analytics and Datastream. If these gains are large, they can affect the location of trading and the relative importance of time zone differences, local market liquidity or illiquidity, and regulatory determinants of the location of trading. The effect is similar to reductions in transaction costs of buy and sell orders involving counterparties in different locations. Lower costs may encourage onshore transactions to move offshore to the largest, most liquid financial centers.[23] But the effect could also go in the opposite direction, to the extent that cable connections give the local sales desk access to a more timely and broader set of quotes as well as other financial information and enable them to communicate more easily with matching servers offshore.[24]

[22] EBS is predominantly used for transactions involving the US dollar, euro, yen and Swiss franc, while Thomson Reuters is predominantly used for transactions involving the pound sterling, the Australian, Canadian and New Zealand dollars, and emerging market units.

[23] This liquidity effect may be self-reinforcing in the manner of the standard "home market effect" (Krugman 1980, 1995). The analogy is that exchange rate trading is similar to production of services under monopolistic competition – i.e. the restricted number of electronic platforms or number of FX dealers that dominate the market – and increasing returns arising from the self-reinforcing effect of greater market liquidity. The production in question moves to the largest market when transportation costs are lowered, i.e. when bandwidth is increased through cable connections. A difference from Krugman (1980)'s model is that he considered two types of goods of different varieties whereas we focus here on one type of services, i.e. foreign exchange transactions in different units. In a related model, Gehrig (1998) observes that a decline in transportation costs strengthens the impact of thick market externalities and the position of incumbent markets.

[24] To continue with the analogy with Krugman's model discussed above, production of the varieties of the differentiated good or service in question becomes more domestic when their fixed costs of production are reduced.

Our analysis takes advantage of heterogeneity across countries and over time in when different countries were connected to the network of submarine fiber-optic cables, either directly or indirectly. Here "directly" means that there is a point-to-point submarine fiber-optic cable connecting country x to the UK, US or Japan.[25] "Indirectly" means that country x is connected to country y and country y is in turn connected to the UK, US or Japan. In practice we take into account indirect connections up to the ninth order.

Figure 2 shows the year of first direct or indirect connection to the UK, US or Japan. France and the Netherlands were connected to the UK in 1989. South Africa, to take a contrasting example, was connected much later, in 2002. Landlocked countries, like Switzerland or Hungary, are not connected by submarine cables for obvious reasons. We hence use for identification both the cross-section and time series dimensions, i.e. heterogeneity between landlocked countries and nations bordering the sea and heterogeneity between the period pre-2002 and the period post-2002. (In robustness checks we show that our results are robust to alternative sample periods).[26]

VI. HYPOTHESES

We estimate the determinants of the share of foreign exchange trading occurring offshore as a function of cable connections and control variables.[27] We account for the possibility of unobservable random and time effects by estimating the following specification:

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[25] In robustness checks we consider only connections to the UK, the US and Japan individually; see below.

[26] Landlocked countries can be connected only indirectly via terrestrial cables. This entails higher costs, since digging trenches, tunneling through natural obstacles and obtaining transit rights from property owners are costly and difficult (as recounted by Lewis 2014) – more costly and difficult than laying cables on the seabed. Figures A4 and A5 illustrate the growing density of the submarine cable network. They show the network of countries directly or indirectly connected to the UK in 1998 and 2013, respectively. Countries in time zones corresponding to Asian trading hours are shown as light grey nodes, against grey nodes for those located in time zones corresponding to European trading hours and dark grey nodes for US trading hours. Solid lines indicate countries with liquid units – those that are in the top third by FX turnover – while dashed lines are units in the middle third, and dotted lines are illiquid units in the bottom third. The contrast between the two figures is striking. That the network of connections to the UK has grown markedly over time, and improved access to the matching servers of EBS and Thomson Reuters for electronic trading is readily apparent.

[27] Descriptive statistics of the data used to estimate our model equations are provided in Table A16 in the online appendix.

$$y_{i,t} = \boldsymbol{\beta}'\mathbf{Z_{i,t}} + \boldsymbol{\varphi}'[\mathbf{Z_{i,t}} \times Cables_{i,t}] + \gamma Cables_{i,t} + \boldsymbol{\rho}'\mathbf{X} + \alpha_i + \lambda_t + \varepsilon_{i,t} \qquad (1)$$

where i and t denote currency and time; y is the share of trading occurring offshore for currency i in year t. $\mathbf{Z}$ = [*Time Zone Distance*$_i$, *Domestic Market Liquidity*$_{i,t}$, *Capital Controls*$_{i,t}$] is a vector of financial and geographical frictions whose effect on the location of trading may be affected by the presence of a cable connection. *Cables* is a zero/one dummy variable for the existence of a cable connection between the country issuing currency i and London, New York or Tokyo in a given year t. $\mathbf{X}$ is a vector of additional controls. The vectors $\boldsymbol{\beta}$, $\boldsymbol{\varphi}$, γ and $\boldsymbol{\rho}$ are the parameters to estimate. The α_i are random effects and λ_t are time fixed effects.

We estimate Eq. (1) using a panel tobit estimator and a panel generalized linear model with a logit link (both with random effects). Tobit is appropriate insofar as our dependent variable is a share whose observed range is censored below zero and above 100 percent. We also report results using linear panel and pooled OLS estimators, with standard errors robust to heteroskedasticity and clustered by trading zone,[28] The time (survey-year) fixed effects soak up variation in the data due to unobserved global factors such as the rise of financial institutions' proprietary trading at the expense of corporates, the emergence of algorithmic trading and co-location services in the mid-2000s, or regulatory changes (more on this below).

The first determinant we consider is distance. An interpretation of its effect is in terms of the costs of obtaining information or doing business to which it gives rise.[29] One mechanism is that traders outside the country of issuance face an information

[28] These estimates do not take into account the boundedness of the dependent variable. We distinguish the three time zones corresponding to Asian trading hours, European trading hours and US trading hours. We effectively assume that observations within time zones are correlated in an unknown way but that observations across time zones are uncorrelated. This allows us to take into account variations in liquidity over the trading day and across time zones, as discussed e.g. in Bollersev and Domowitz (1993) and Huang and Masulis (1999). Moreover, insofar as time zone distance is constant over time, its effect can no longer be estimated if we use OLS with fixed effects. This is why our baseline estimators are panel Tobit and GLM with random effects.

[29] Such information asymmetries are key to exchange rate determination in the analysis of Bachetta and van Wincoop (2006) and to the vehicle role of a unit in the model of Lyons and Moore (2009).

disadvantage and trade less profitably (Hau 2001). Onshore traders possess more and better information than offshore traders who are distant from local sources of public information, such as central banks, or private information, such as customer-order-flows (Menkhoff and Schmeling 2008).[30] Fiber optics level the playing field by cutting the cost of obtaining information from afar. Time zone distance rather than physical distance is what matters for the location of information-intensive activities (see e.g. Bahar 2019). Non-overlapping trading hours increase the cost of doing business. Liquidity in the foreign exchange market varies significantly over the trading day and across time zones, being highest when European and US trading sessions overlap (see Bollersev and Domowitz 1993 and Huang and Masulis 1999).[31] Moreover, prior to fiber-optics, traders in distant time zones did not receive news, market commentaries and buy and sell orders simultaneously, unlike traders in the same or adjoining time zones. Fiber optics help to relax barriers to information flows, data processing, and matching buy and sell orders arising from time zone differences.[32] More information can be accessed anytime, anywhere, and larger amounts of data and orders can be matched and aggregated.

Our basic measure of distance, therefore, is time zones between the country issuing currency *i* and either London, New York or Tokyo, whichever is closest to the country in question.[33] This choice is consequential: Johannesburg, for example, is more

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[30] In contrast, the "financial center" hypothesis (Hau 2001) suggests that traders in large financial centers enjoy an information advantage. They have access to proprietary data bases and in-house research creating economies of scale and scope. They benefit from a larger customer base and better access to private information about order flows, which may also help them to forecast and exploit the trading interests of smaller traders (Moore and Payne 2011). They may reside in larger trading rooms and hence enjoy informational spillovers from colleagues trading, inter alia, fixed-income securities and equities.

[31] This matter for computer-run algorithmic or automated trading strategies seeking to transact with sleeping agents, this factor being emphasized in studies of the microstructure of the foreign exchange market such as in e.g. Bollersev and Domowitz (1993) and Huang and Masulis (1999).

[32] Contrasting the effects of physical distance with those of time zone distance provides a placebo test of the two mechanisms we have in mind. Insofar as fiber-optic connections affect the geography of FX trading mainly through higher bandwidth, they should not impact the effect of physical distance on the share of foreign exchange transactions occurring offshore to the same extent than time zone differences. The reason is that physical distance is correlated with latency but not bandwidth (the correlation is positive: the longer the cable between two geographical points, the higher the latency). Our estimates are consistent with this interpretation, as we show below.

[33] This means that there is one measure of distance relative to either London, New York or Tokyo per country. We use coordinated universal time, computed from the country's financial center time zone

than 13,000 kilometers away from London but only one time zone ahead. We expect that $\beta_1 < 0$.

The second determinant we consider is domestic market liquidity. More liquid markets allow transactions to be undertaken at lower cost. Buy and sell orders can be matched more seamlessly. Bid-ask spreads are narrower, and traders can buy and sell larger blocks without moving prices. Where local markets are small and illiquid, the agglomeration economies and thick-market advantages of offshore markets like London, New York or Tokyo known for their depth and liquidity will be particularly strong. Conversely, where local markets are liquid, they are likely to capture a larger share of trades.[34] Prior to fiber optics, traders in local markets could not easily seek liquidity elsewhere using traditional means of dealing, like voicing trading. They could not easily match their buy and sell orders with market participants trading from afar. With the advent of fiber optics, they can access a larger pool of quotes and match buy and sell orders with offshore traders more easily, reinforcing the thick-market advantages of major financial centers.

Our measure of domestic market liquidity is the volume of transactions in foreign currencies in country issuing currency *i* in year *t* (in USD trillion).[35] In the baseline model we exclude transactions in the domestic currency in order to avoid endogeneity with respect to the dependent variable. We anticipate that $\beta_2 < 0$; transactions in units issued by countries with relatively deep and liquid domestic financial markets tend to be undertaken onshore.[36]

The third determinant is restrictions on capital flows. The direct effect of tighter capital controls is to increase the cost of trading offshore. However, Friedman (1969) argued that taxing financial transactions onshore provides incentives for business to migrate offshore (where capital controls are equivalent in this context to a tax on

(New York for the US, Sydney for Australia, Shanghai for China, etc.) and take hour distance between London and Frankfurt for the euro.

[34] This can also be rationalized by referring to models in which concentration of an activity in a particular location has positive feedbacks on the advantages of further concentrating that activity in that location. See the models and arguments of Krugman and Venables (1995, 1996).

[35] We take the total volume of transactions in euro area members for the euro.

[36] In robustness checks, we also consider the logarithm of this variable, as well as the volume of transactions in all currencies (both foreign and domestic).

purchases and sales of a foreign currency).[37] The idea that controls encourage the development of offshore currency markets is widely argued by market participants (see e.g. HSBC 2011 and Credit Suisse 2013).[38] In some cases these offshore markets have developed through trading in non-deliverable forward contracts, which enable investors there to actively trade claims indexed to a currency despite controls maintained by the issuing country that limit their access to the underlying currency itself (McCauley, Shu and Ma 2014).[39] The advent of fiber optics further enables traders to circumvent capital controls by lowering the costs of doing business with offshore traders.

As a measure of restrictions on capital flows, we use the time-varying indices of de jure capital account openness of Fernandez et al. (2015). These capture the overall importance of capital controls in country issuing currency i and in year t.[40] We anticipate that $\beta_3 < 0$; transactions in units issued by countries with closed capital accounts have a higher share of foreign exchange trading onshore. In robustness checks we separate controls on inflows and outflows.

In sensitivity tests, we control for other variables (denoted **X** in Eq. 1 above) whose omission from the baseline specification could conceivably bias the results. These include trade openness (exports plus imports scaled by GDP, constructed from IMF data); financial openness (net external financial assets scaled by GDP, using updated data from Lane and Milesi-Ferretti 2007); a dummy variable for exchange rate flexibility which equals one if a country has a managed exchange rate or a float and zero otherwise, constructed using the updated classification of Ilzetzki, Reinhart and

[37] His example illustrating the power of this hypothesis was the development of the Eurodollar market in London as a response to the adoption by the US of Regulation Q in the 1960s.

[38] For instance, entities that are not registered in China are not allowed to participate in onshore foreign exchange transactions of renminbi (also known as “CNY”), which must be executed via designated foreign exchange banks. Offshore entities can receive and pay renminbis to settle trade in goods transactions under certain conditions, however. This has contributed to the development of an offshore market of renminbis in Hong Kong (also known as “CNH”) in the 2000s in which the renminbi can be freely transferred between accounts and across banks (although transfers to/from the mainland remain tightly regulated).

[39] Non-deliverable forwards are forward exchange agreements settled with a single US dollar payment. They hence allow market participants to obtain exposure to the underlying local unit without having to deliver it (unlike deliverable forwards). Transactions in non-deliverable forwards are included in the BIS data.

[40] The index runs from zero (no controls) to one (full controls). For the euro we take the average of the index for the euro area members.

Rogoff (2004); and a metric of dollar-funded carry trades, namely the difference between the short-term local-currency interest rate on currency i and in year t and the corresponding US interest rate.[41]

Our baseline measure of technology *Cables* is a dummy variable that equals one if the country issuing currency i is connected directly or indirectly by a fiber-optic submarine cable to the UK, US or Japan (the three countries where matching servers of EBS and Thomson Reuters are located) and zero otherwise. In robustness checks, we consider point-to-point connections only, the number of separate cable connections and connections only to the UK, New York and Tokyo, respectively.

Our test of the effect of technology on the geography of the foreign exchange market considers the following null hypothesis:

$$H_0 : \gamma = 0 \text{ or } \forall\, j = 1,2,3, \varphi_j = 0.$$

Rejecting the null hypothesis suggests that technology has an impact on the geography of the foreign exchange market that can be direct, as captured by the coefficient γ, or indirect, i.e. via the interacted determinants of foreign exchange trading occurring offshore, as captured by the vector of coefficients $\boldsymbol{\varphi}$. The signs of γ and of the $\boldsymbol{\varphi}$ coefficients indicate whether the cable connection increases or reduces trading occurring offshore through its direct effect on the costs of trading and whether it dampens the impact of standard determinants such as distance, domestic market liquidity and capital controls on attracting foreign exchange trading onshore, as discussed above (i.e. we expect $\boldsymbol{\varphi} > 0$). The net effect from the different coefficients indicate whether cable connections cause trading to move offshore to major financial centers or not.

VII. RESULTS

[41] We used money market rates (and Treasury bill rates when they are not available). In robustness checks we also obtained estimates using proxies of yen-funded carry trades, which gave similar results.

Table 1 reports estimates of equation 1 without the cable variables. Panel tobit estimates with random effects are reported in columns 1 and 2; panel GLM estimates are in columns 3 and 4; linear panel estimates with random effects are in columns 5 and 6; and pooled OLS estimates with country fixed effects are in columns 7 and 8. Standard errors in columns 3 to 8 are robust to heteroskedasticity and those in columns 5 to 8 are clustered by time zone. Time fixed effects are included in all columns.

The results for the baseline specification in column 1 suggest that the effect of distance on the share of trading offshore is negative and statistically significant, consistent with the "local information" hypothesis. The point estimate suggests that each hour difference relative to the US, the UK or Japan lowers the share of offshore trading of the currency issued by the country located in the time zone in question by 12 percentage points.

The estimated effect of domestic market liquidity on offshore trading is also negative, as anticipated, and significant. The coefficient in column 1 implies that the share of offshore trading of a currency issued by a country where the volume of local FX transactions is USD 250 billion larger (a large amount by today's standards) is about 10 percentage points lower.[42]

The effects of capital controls are more varied. The panel tobit estimates in columns 1 and 2 suggest that their effect is insignificant, as do the panel GLM and pooled OLS estimates of columns 3, 4, 7 and 8.[43] The linear random-effects estimates in columns 5 and 6 suggest that the impact of controls is negative and significant. This is in line with the prior that capital controls increase the cost of trading offshore.

Estimates controlling for trade integration, financial integration, the exchange rate regime and carry trades are similar (see column 2 of Table 1). So are the panel GLM and linear panel random-effects estimates (in columns 3 to 6 of Table 1). The

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[42] Recall that domestic market liquidity is expressed in $trillion. $250 billion is not too far off the volume of offshore FX trading in Singapore or Zurich as of 2013. Readers will remember that we exclude here transactions in domestic currencies from the metric of domestic market liquidity to avoid spurious correlations. This result may possibly reflect agglomeration effects arising in a self-perpetrating way, as in Krugman and Venables (1995, 1996). It is also consistent with models emphasizing financial frictions, such as the limited risk-bearing capacity of financiers or international imbalances in the demand for financial assets, as in Gabaix and Maggiori (2015).

[43] He et al. (2015) analyze a smaller cross-section of currencies and a different specification, but they too find no statistically significant impact of capital controls.

coefficient on exchange rate flexibility is positive and significant. The coefficient on carry trades is negative and also significant, which suggests that high local interest rates relative to the US encourage market participants to invest in local money markets and exchange funding in dollars, yen (or another low-interest rate unit) against local currency onshore to that end.

Figure 3 turns to the impact of technology using an event study. It shows the average share of offshore foreign exchange transactions in the economies of the sample in 3-year intervals prior and after connection to the internet backbone (the length of the intervals corresponds to the number of years between waves of BIS triennial surveys). The share in question is stable –or falling– before connection. And it increases substantially in the interval immediately after connection, which suggests that fiber-optics tends to boost overall foreign exchange trading occurring offshore.

Table 2 examines this finding more in depth and reports estimates where the share of foreign exchange trading taking place offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effect of a submarine fiber optic cable connection to the UK, the US or Japan.[44]

Consider again the panel tobit estimates in columns 1, 2 and 3. The main findings of Table 1 remain broadly unchanged, with the estimated coefficients now being if anything larger in economic magnitude.[45] The unconditional effect of a cable connection is positive and statistically significant, confirming that fiber optics tend to boost overall foreign exchange trading occurring offshore (see column 1).

The economic mechanism becomes clearer with the conditional estimates (see columns 2 and 3). The conditional effect of a cable connection is negative and statistically significant, unlike the unconditional effect. This implies that a cable connection makes it more likely that a country will be able to retain or repatriate trading in its currency at home, other things being equal. An interpretation is that costs of

[44] Both point-to-point connections and connections via third countries, recall, are considered here (in columns 2 and 3 respectively). Again, panel tobit estimates with random effects are reported in columns 1, 2 and 3; panel GLM estimates are in columns (4) and (5); linear panel estimates with random effects are in columns 6 and 7; and pooled OLS estimates with currency fixed effects are in columns 7 and 8.

[45] As a result the negative effect of capital controls is also statistically significant at the 20% level of confidence.

trading locally are lower because local sales desks can now more efficiently communicate with the matching servers in offshore financial centers and access other internet-based applications, rendering them more competitive.

But the interacted effects of submarine fiber optic connections, which operate through distance, domestic market liquidity and capital controls, are also statistically significant.[46] They go in the opposite direction from the direct effect of fiber optic connections (they enter with a sign opposite to the sign of the connections variable when it is not interacted with the other determinants).

The results are similar with a panel GLM estimator (see columns 4 and 5). Overall, they suggest that the negative effect on the share of a currency traded offshore of distance is smaller (in absolute value) in the presence of a cable link. The negative effect of a relatively liquid local market is smaller (in absolute value) in the presence of cables. The negative effect of capital controls is again smaller in absolute value. Thus, where the direct effect of a cable link to one of the three major centers enables a country to retain more transactions in its currency onshore, the indirect effect is to weaken other factors (distance, local market liquidity, capital controls) that previously segmented markets and gave it a locational advantage.

Figure 4 shows the predicted share of offshore FX trading conditional on time-zone distance when other spatial determinants are set to zero with cable connections (the solid line) and without (the dashed line).[47] The left-hand side is based on the tobit estimates reported in column 2 of Table 2; the right-hand side is based on the panel GLM estimates reported in column 4 of Table 2.

Consider the tobit estimates first. That a cable connection attenuates the effect of distance and local information is evident from the fact that the solid line (with cable) is flatter than the dashed line (without cable). For a country close to one of the financial centers, the main impact of the cable connection is direct; it allows the country to retain a larger share of trading in its currency (toward the left-hand side of the figure the solid line is below the dashed line, indicating that a smaller share of transactions occur offshore in the presence of a cable). South Korea, for example, is in the same time zone

[46] At the 20% level of confidence for capital controls.

[47] The time effects – which range from zero in 1998 and 70% in 2013 – are also set to zero.

as Japan, where the Korean won is among the currencies least traded offshore. Conversely, for a country far from one of the financial centers, the main impact of the cable connection is indirect; it works to erode the advantages of distance, causing the country to lose a larger share of trading in its currency to offshore markets (toward the right-hand side of the figure, the solid line is above the dashed line, indicating that a larger share of transactions occur offshore). This is the case of New Zealand, for example, which is three hours ahead of Japan and whose unit is heavily traded offshore.

At a distance of three hours, our tobit estimates suggest that the share of foreign exchange occurring offshore should be negative. The dependent variable is bounded between zero and one, which implies that quasi-linear estimates such as those obtained with tobit only approximate the true effects of the predictors around the dependent variable mean. Fitting the response variable with large predictor values hence may result in predicting expected shares outside the [0,1] domain, as it is the case here. This problem is familiar from other applications, such as in medical science and epidemiology, which has encouraged scholars to obtain panel generalized linear model (GLM) estimates with a logistic link function and a binomial distribution, as we do here (see Localio, Margolis and Berlin 2007 and Diaz-Quijano 2012).[48] This approach allows the logistic transformation of the fitted response to vary linearly with the predictors while keeping the predicted share between zero and one. Consider now the right-hand side of Figure 4. That a cable connection attenuates the effect of distance and local information over the relevant range is again evident from the fact that the solid curve (with cables) is flatter than the dashed curve (no cable).

The crossover point is at roughly one hour. For countries in the same time zone as one of the three big financial centers, a cable connection is a positive for the market share of local sales desks. For countries two or more time zones away, the net effect on the local sales desk is negative.

How large is the effect on average? Taking the ratio in percentage terms of the slopes of the two lines obtained from the tobit estimates suggests that the effect of hour distance on the share of foreign exchange trading occurring offshore is 78% lower on

[48] We also obtained very similar results with a probit link function in robustness checks.

average in countries connected to a submarine fiber-optic cable relative to countries that are equally distant from a major financial center but not connected.[49]

Figure 5 illustrates the extent to which the attractions of deep and liquid domestic markets are lessened by cable connections, constructing predicted shares in the same manner. Once more the solid line is flatter than the dashed line. For a country whose domestic market is relatively illiquid, the direct impact of the cable, in leading to the retention or repatriation of business onshore, is the main effect. But a cable connection also attenuates the advantages of a highly liquid domestic market. Countries that previously saw a relatively high share of transactions in their currency occurring onshore due to domestic market liquidity may see a decline in that share with a cable connection. An example is Australia, which was connected in 2001 and saw the share of its currency trading offshore jump by seven percentage points in the three subsequent years, despite the fact that domestic market liquidity increased by 28% over the same period.

Again, how large is the effect on average? Taking the ratio in percentage terms of the slopes of the two lines obtained from the tobit estimates suggests that the effect of domestic market liquidity on the share of foreign exchange trading occurring offshore is 80% lower on average in countries connected to a submarine fiber-optic cable than in countries with equally liquid domestic markets but not possessing a cable connection.

Figure 6 depicts the extent to which technology neutralizes the effect of capital controls.[50] Again the solid line is flatter than the dashed line, indicating that a cable connection attenuates the effect of controls.[51] A cable connection reduces the share of trading in a currency that occurs offshore through its direct effect; tighter controls would be expected to bottle up more of this business, but their impact is weakened by a cable connection, this being the cable's indirect effect. This time, however, the solid

[49] For the panel GLM estimates cable connection also reduces considerably the economic importance of distance, although the reduction rate is now nonlinear and varies with distance itself.

[50] We do not report the panel GLM estimates here because the interaction between cable connection and capital controls was not statistically significant.

[51] Intuitively one might interpret this as cable communication opening up additional channels for evasion.

line is entirely below the dashed line due to the cable's direct effect.[52] But the effect of capital controls on the share of foreign exchange trading occurring offshore is still 83% lower on average in countries connected to a submarine fiber optic cable relative to countries equally open financially but not connected in this manner.

VIII. INSTRUMENTAL VARIABLES

As a robustness check, we use the ruggedness of the seabed and the 3-dimension length of the submarine fiber-optic cables as instruments for the existence of cable connections. Seabed ruggedness captures the existence of domes, canyons, faults, and other topological irregularities. Laying a submarine cable between two points on the sea floor is more costly in the presence of such irregularities; they should therefore affect the location of cables and the timing of investments.[53] Insofar as irregularities arise from nature, they provide a source of variation that is exogenous to financial and economic activities. There is no other obvious reason why seabed ruggedness should affect the location of foreign exchange trading. This measure should therefore satisfy both the relevance and exclusion restrictions for a valid instrument.

In a related paper, Juhász and Steinwender (2018) show that ruggedness of the sea floor predicts when countries were connected to the telegraphic network in the 19th century.[54] In their spirit, we constructed the ruggedness instrument using a 30 arc-second grid of elevation for oceans data from the General Bathymetric Chart of the Oceans (GEBCO).[55] We computed the shortest undersea route between the two endpoints of the first undersea cable linking country *i* and the major financial center

[52] This is evident from Table 2, where the coefficient on capital controls interacted with cables is always smaller than the coefficient on controls, and the controls measure varies between zero and one.

[53] These considerations are discussed by technical specialists; see e.g. Clark (2016) and Ye, Jiang, Pan and Jiang (2018).

[54] Less directly related, Nunn and Paga (2012) show that the ruggedness of land in Africa has had positive effects on income insofar as rugged terrain afforded protection to those being raided during the slaves trade, which is thought to have retarded economic development.

[55] At the equator, an arc-second of longitude approximately equals 1/60th of a nautical mile (or about 101 feet or 31 meters). Arc-seconds of latitude remain nearly constant, while arc-seconds of longitude decrease in a trigonometric cosine-based fashion as one moves toward the earth's poles.

located in the closest time zone (i.e. London, New York or Tokyo).[56] We defined a 25 kilometer buffer along both sides of the shortest route and computed the average ruggedness measure of Riley et al. (1999) within this buffer. The measure is defined as the square root of the sum of the squared differences in elevation between a point and its 8 neighbors in the major directions of the compass (i.e. north, northeast, east, southeast, south, southwest, west, and northwest).[57]

The other instrument we consider is the logarithm of the 3-dimensional (3-D) length of individual cables. This measure accounts for topological irregularities on the seabed along the shortest route, also taken from Juhász and Steinwender (2018). Technical sources cited above support the notion that the longer the cable's length – in a 3-dimensional sense – the more technically difficult and costly is it to lay that cable on the seabed.

We consider each variable individually, jointly and their interaction as regressors in the first-stage where the dependent variable is the year when a country was connected to the internet backbone.[58] The F-statistic of the first-stage regression is over 12 when use 3-D cable length as instrument (see Table A3 in the online appendix), indicating more than adequate strength.[59]

When we used the year of connection predicted by the instruments in question – rounded to the nearest integer – in a second-stage regression, we obtained similar results as our basic estimates (see Table 3). Hence the dampening effect of cable connections on the standard gravity trade determinants is robust to the instrumental variable strategy and can be interpreted as causal.

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[56] We used the aquaplot.com API to compute the routes in question on high-resolutions maps (e.g. allowing the shortest routes to go through narrow water paths, such as the Suez and Panama canals).

[57] More formally, let $e_{r,c}$ denote elevation at the point located in row r and column c of a grid of elevation points; ruggedness at that point is computed as $\sqrt{\sum_{i=r-1}^{r+1} \sum_{i=c-1}^{c+1} (e_{i,j} - e_{r,c})^2}$. We then average across all grid cells along the route to obtain the average ruggedness measure.

[58] Figures A6 and A7 in the online appendix show that ruggedness and 3-D length are both correlated positively with the year of connection to the network of submarine fiber-optic cables, in line with our priors. The IV estimates exclude the two countries already possessing cable connections in 1989 insofar as our first-stage regression aims to predict year of cable connection over our sample period 1995-2013.

[59] Power of the other instrument or combination of instruments is weaker, so we focus on 3-D cable length.

IX. ROBUSTNESS

Table 4 reports additional sensitivity checks, where we use a time trend in lieu of time fixed effects (column 1); cable connections interacted with a time trend (column 2)[60]; geographical distance instead of the time difference to the UK, US or Japan (column 3); the log of FX turnover rather than its level (column 4); total FX turnover rather than FX turnover net of domestic currency turnover (column 5); restrictions on capital inflows rather than restrictions on all flows (column 6); restrictions on capital outflows (column 7); and initial values of the standard determinants of the location of foreign exchange trading (column 8). Our findings remain robust.

In particular, Table 4 reports the results of a placebo test using physical distance in lieu of hour distance. The coefficients on physical distance and its interaction with fiber optic connections are statistically insignificant, in line with the interpretation that the effect of the internet backbone works through higher bandwidth. Column 7 then shows that the effect of technology on capital controls mainly goes through restrictions on outflows rather than inflows.[61]

The online appendix contains a battery of additional robustness checks. For example, we again find evidence of mitigating effects of fiber optic connections on the standard determinants of where currencies are traded when we restrict the estimates to shorter samples ending in 2010, 2007 or 2004 (Table A4 in the online appendix).

Conceivably, wider data coverage over time might affect our dependent variable and bias our estimates. We therefore estimated the same relationship on a balanced sample restricted to currencies reporting trading location since 1995. Although we lose half the observations, the estimates are essentially the same in terms of sign, statistical significance and economic magnitude (Table A5 in the online appendix). Only the point estimates on capital controls and on its interaction with cable connections lose

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[60] We therefore control for the fact that our cable connection variable could just be picking up other global changes insofar as cable connectivity is positively correlated with time. And the results again suggest that our findings are not contaminated by unobserved global changes.

[61] We also examined bilateral data published by the BIS where we could look directly at offshore trading in London, Tokyo and New York for a small number of advanced economy units. However, their countries of issuance were almost all connected to the internet backbone simultaneously, implying that there was hardly any variation to exploit for identification.

their previous statistical significance, possibly reflecting the loss in efficiency resulting from the smaller sample (see Table A5).

We tested for parameter instability, using Chow tests for structural breaks in 2001, 2004 and 2007. The results (see columns 3 to 5 of Table A6 in the online appendix) show that changes in the interacted coefficients after the break are generally insignificant statistically. Where they are significant, they point to slightly larger economic effects (the coefficient on the interaction between cable connections and time zone distance increases from about 0.3 to 0.4 for example).

We also controlled for time averages of the exogenous variables (Table A7 in the online appendix). While the averages are jointly significant, the estimated coefficients do not change in terms of sign, economic magnitude and statistical significance (columns 1 and 2 as well as columns 3 and 4 of Table A7). This suggests that even if our baseline estimates do not fully control for unobserved heterogeneity, any bias is small. In addition, pooled Tobit estimates with fixed effects are broadly in line with the basic estimates (columns 5 and 6 of Table A7)

We dropped observations from each year of the BIS triennial survey in turn in order to test whether our findings are driven by a particular year or years (Table A8 in the online appendix). The interacted coefficient on capital controls loses its statistical significance in some years. The interacted coefficient on domestic market liquidity loses its significance when we drop the observations for 1998 and 2010. Overall, however, the results remain robust.

We next dropped individual countries from the sample one at a time to see whether the results were being driven by influential national cases. The estimates are robust (Table A9 in the online appendix). We re-estimated the key relationships controlling for offshore centers (i.e. countries on the list of non-cooperative jurisdictions designed by the IMF, OECD, the Financial Secrecy Index or other sources, such as the EU), taking data from Chiţu et al (2014). The results are unchanged (column 2 of Table A10 in the online appendix). We also tested whether the coefficients on cable connections were different for offshore centers than other countries, which is not the case (column 3 of Table A10). As we stress in the paper, undersea fiber optic cables have been laid mostly for reasons unrelated to trading; they were laid not because these islands are tax heavens but, rather, because they have favorable seabed topology.

We split cable connections into connections to London only, New York only, and Tokyo only. The results are robust (see Table A11 in the online appendix).

We also explored potential nonlinearities in the role of capital flow restrictions. We asked whether the coefficients on the cable variables were different for countries with stricter capital controls relative to other countries using binary dummies which equal one if a country is among the top-30%, 20% and 10%, respectively, of the capital control distribution in a given year, and zero otherwise. This is not the case (see Table A12 in the online appendix).

We estimated whether the coefficients on the cable variables were different for major currencies, using binary dummies which equal one if a currency is a global reserve unit (US dollar, euro, yen, Swiss franc and pound sterling) or among the G10 units (the same currencies along with the Norwegian krone, the Swedish krona, the Australian, New Zealand and Canadian dollars). This is not the case insofar as the interacted coefficients are mainly insignificant, with the exception of the one on capital controls (see Table A13 in the online appendix).

Table A14 in the online appendix reports estimates when the share of foreign exchange traded offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effect of exclusively point-to-point submarine fiber-optic cable connections with the UK, US and Japan (as opposed to including also cable connections to the UK, US and Japan via third countries).[62] Our results remain broadly unchanged in terms of sign, statistical significance and economic magnitude.[63] Table A15 in the online appendix then reports the estimates when we use the number of connections to submarine fiber-optic cables as our measure of technology. Again our main results are broadly unchanged.[64]

[62] Convergence of the panel GLM estimates were here obtained with a probit (rather than logit) link function.

[63] The exception is the effect on capital controls, which loses statistical significance.

[64] The exception is again the effect on capital controls, which loses statistical significance. Note also that the estimated coefficients on the interacted effects are smaller in economic magnitude, which is due the fact that our measure of technology is a continuous variable rather than a binary dummy as in Tables 2 and 3. Convergence of the panel GLM estimates with the additional controls was not obtained.

X. DISTRIBUTIONAL EFFECTS

Finally, we inquire into the impact of cable connections on the location of foreign exchange trading among the world's financial centers. First, we estimate the net impact of cable connections on the share of offshore foreign exchange transactions using the panel GLM estimated coefficients in column 4 of Table 2. We also predict shares under a counterfactual where issuing countries are not cable-connected (i.e. by setting the coefficient γ and those in vector $\boldsymbol{\varphi}$ to zero). The difference between the predicted and estimated counterfactual shares is the net effect of cable connections in percentage points by currency. The net effect is converted into transaction volumes using actual turnover for each currency.

The results are shown in Figure 7 based on 2013 data. The dampening effect of cable connections on spatial determinants generally dominates the reduction in the costs of trading currencies locally in net terms; the share of offshore trading is higher for most units. The cross-currency average suggests that cable connections increase, in net terms, the share of offshore trading by about 21 percentage points.

One exception is the Canadian dollar, whose offshore share declines by 10 percentage points. This is intuitive: Toronto is in the same time zone as New York, the Canadian forex market is relatively thin, and Canada is open financially. There are few spatial determinants to attenuate, in other words, so only the reduction in the costs of trading locally remains. A similar story pertains to the Korean won.

The New Zealand dollar and Indian rupee are contrary cases: their offshore shares both increase by about 50 percentage points. These units are issued by the two countries most remote from the major financial centers. Hence the dampening effect of cable connections on distance is substantial.[65]

The shares of the US dollar, the euro and sterling also increase substantially, similarly reflecting the mitigating effects of cable connections on distance and on the attractions of their large and liquid local foreign exchange markets. The shares of the Swiss franc and Hungarian forint, in contrast, do not change, which is again intuitive:

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[65] New Zealand is three hours ahead of Tokyo while India is four hours behind.

Switzerland and Hungary are landlocked and have no submarine fiber-optic cable connections.

In the second step, we allocate net gains and losses in the volume of offshore trading by currency between financial centers. We have total net volume estimates by currency. (Unfortunately, we are not able to split these estimates by both currency and financial center. In other words, we know by how much trading volumes move offshore, but we do not know exactly to where.) We therefore allocate the counterfactual offshore trading volumes across financial centers proportionately to their actual shares in global foreign exchange turnover in 2013. Thus, if the UK accounts for 42% of global foreign exchange turnover, it receives 42% of the counterfactual net gains in the volume of offshore trading by currency.[66]

Figure 8 shows the net percentage point change in the share of global foreign exchange turnover by country. The main losers from cable connectivity are Frankfurt and other euro area financial centers and, perhaps surprisingly, New York, with losses of seven and five percentage points of global foreign exchange turnover, respectively. Cable connections cause transactions in the dollar and the euro to move offshore, i.e. away from New York and Frankfurt but in addition lead to the geographical redistribution of a relatively large *volume* of foreign exchange transactions, insofar as the dollar and the euro are two of the principal currencies traded in foreign exchange markets. The volume of transactions in other currencies that move *to* Frankfurt and New York from other financial centers, in contrast, is much smaller.

The main winner overall is the UK, with a gain of 10 percentage points of global foreign exchange turnover due to cable connectivity. Other centers affected positively include Japan and Singapore, with gains of about one percentage point each. While London, Tokyo and Singapore are all major financial centers for foreign exchange trading, their own currencies are not traded as heavily as the euro and the dollar. Thus, what London, Tokyo and Singapore lose when trading in their respective units moves

[66] Onshore trading volumes in the currency in question are reduced accordingly so that global turnover remains unchanged. A more extreme assumption would be to allocate net gains only to London, New York and Tokyo (i.e. to consider only point-to-point connections rather than also indirect connections). But that would only magnify the sizeable boost to the global market share of London and Tokyo which we document below.

offshore is more than compensated for by the trading in other units that cables allow them to take away from other financial centers.[67] That the winners are islands (or a peninsula in the case of Singapore) is a reminder that the advantages afforded by cable connections have deep geographical roots, which underscores their exogeneity.

These changes are economically important. The increase of 10 percentage points of the share of London in global foreign exchange turnover is equivalent to a one-third increase relative to the counterfactual when it has no cable connections. In contrast, Switzerland's share stays constant since it has no submarine cable connection.

XI. CONCLUSION

Employing data on trading of 55 currencies between 1995 and 2013 and the inauguration of submarine fiber-optic cables as a source of exogenous technological change, we estimate the impact of cable connections on the share of offshore foreign exchange transactions. We find that the dampening effect of cable connections on spatial determinants dominates the reduction in the costs of trading currencies locally. Cable connections lead to an increase in the share of offshore trading for most units.

The dampening effect of cable connections on the standard gravity trade determinants is robust to an instrumental variable strategy using the 3-dimension length of the submarine fiber-optic cables as an instrument. It is robust to a battery of other robustness checks. Our estimates suggest that technology dampens the impact of spatial determinants by up to 80 percent and increases the share of offshore trading by an average 21 percentage points. Technology has economically important implications for the distribution of foreign exchange transactions across financial centers, boosting e.g. the share in global turnover of London, the world's largest trading venue, by an estimated one-third.

[67] An additional explanation in the case of the yen is that the net effect of cable connection is to increase the share of onshore trading.

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Table 1: Estimates with Standard Determinants of the Location of FX trading

	(1) Panel tobit	(2) Panel tobit	(3) Panel GLM	(4) Panel GLM	(5) Random effects	(6) Random effects	(7) Pooled OLS	(8) Pooled OLS
Time zone distance	-0.120*	-0.085+	-0.257	-0.384+	-0.104***	-0.083*		
	(0.064)	(0.060)	(0.263)	(0.271)	(0.036)	(0.049)		
Domestic market liquidity	-0.383***	-0.388***	-1.384***	-1.342***	-0.299***	-0.303***	-0.345**	-0.346***
	(0.093)	(0.095)	(0.391)	(0.201)	(0.015)	(0.016)	(0.038)	(0.033)
Capital controls	-0.109	-0.100	-0.502	-0.525	-0.111**	-0.145***	-0.094	-0.152
	(0.107)	(0.106)	(0.466)	(0.476)	(0.045)	(0.054)	(0.123)	(0.112)
Trade integration		-0.091		-0.249		-0.067+		0.014
		(0.071)		(0.299)		(0.048)		(0.140)
Financial integration		0.094+		0.240		0.044		-0.005
		(0.060)		(0.281)		(0.045)		(0.102)
Flexible exchange rate regime		0.145**		0.765**		0.094***		0.028
		(0.056)		(0.341)		(0.033)		(0.034)
Carry trades		-0.005**		-0.032		-0.002		-0.002
		(0.002)		(0.045)		(0.002)		(0.003)
Constant	0.119	0.124	-1.331**	-1.150**	0.262***	0.275***		
	(0.100)	(0.110)	(0.547)	(0.568)	(0.047)	(0.005)		
Currency effects	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	252	238	252	238	252	238	252	238
R^2					0.252	0.220	0.937	0.939
ρ	0.783	0.740			0.744	0.686		

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading. Panel tobit estimates with random effects are reported in columns (1) and (2); panel GLM estimates are reported in columns (3) and (4); linear panel estimates with random effects are reported in columns (5) and (6); and pooled OLS estimates with country fixed effects are reported in columns (7) and (8). The standard errors reported in parentheses in columns (3) to (7) are robust to heteroskedasticity and those in columns (5) to (8) are clustered by time zone (i.e. Asian, European, and US trading sessions); *** p<0.01, ** p<0.05, * p<0.1, $^+$ p<0.2.

Table 2: Basic Estimates – Impact of Submarine Cable Connections

	(1) Panel tobit	(2) Panel tobit	(3) Panel tobit	(4) Panel GLM	(5) Panel GLM	(6) Random effects	(7) Random effects	(8) Pooled OLS	(9) Pooled OLS
Time zone distance	-0.117*	-0.463***	-0.430***	-1.443***	-1.586***	-0.221***	-0.195***		
	(0.064)	(0.127)	(0.126)	(0.478)	(0.508)	(0.067)	(0.045)		
Domestic market liquidity	-0.358***	-1.757**	-1.784**	-7.746***	-7.047***	-1.270***	-1.104***	-1.761**	-1.676***
	(0.093)	(0.818)	(0.831)	(2.115)	(1.827)	(0.131)	(0.066)	(0.222)	(0.106)
Capital controls	-0.111	-0.289+	-0.288+	-1.358+	-1.650**	-0.119**	-0.197**	-0.102	-0.190
	(0.106)	(0.186)	(0.190)	(0.845)	(0.794)	(0.060)	(0.090)	(0.094)	(0.139)
Cables	0.137**	-0.305***	-0.332***	-1.157**	-1.315***	-0.129	-0.141	-0.160	-0.156
	(0.065)	(0.114)	(0.115)	(0.518)	(0.483)	(0.120)	(0.120)	(0.148)	(0.158)
Cables × time zone distance		0.362***	0.361***	1.320***	1.294**	0.132	0.123	0.141	0.135
		(0.112)	(0.113)	(0.486)	(0.510)	(0.114)	(0.108)	(0.126)	(0.126)
Cables × domestic market liquidity		1.398*	1.415*	6.380***	5.677***	0.986***	0.814***	1.431**	1.342***
		(0.814)	(0.827)	(2.104)	(1.807)	(0.117)	(0.061)	(0.212)	(0.124)
Cables × capital controls		0.241+	0.243+	0.833	1.152+	0.014	0.060	0.033+	0.073
		(0.189)	(0.192)	(0.892)	(0.858)	(0.034)	(0.052)	(0.014)	(0.060)
Trade integration			-0.079		-0.142		-0.064*		0.018
			(0.073)		(0.317)		(0.037)		(0.112)
Financial integration			0.095+		0.155		0.043+		-0.022
			(0.062)		(0.303)		(0.029)		(0.075)
Flexible exchange rate regime			0.128**		0.737**		0.092***		0.023
			(0.054)		(0.346)		(0.035)		(0.033)
Carry trades			-0.004*		-0.026		-0.001		-0.000
			(0.002)		(0.034)		(0.001)		(0.002)
Constant	0.089	0.453***	0.463***	-0.159	0.016	0.405***	0.412***		
	(0.101)	(0.133)	(0.142)	(0.431)	(0.565)	(0.090)	(0.094)		
Currency effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	252	252	238	252	238	252	238	252	238
R^2						0.256	0.213	0.941	0.943
ρ	0.789	0.830	0.799			0.759	0.684		

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effect of both point-to-point and via third countries submarine fiber-optic cable connections to the U.K., U.S. or Japan (i.e. the three countries where the matching servers of EBS/Reuters for electronic trading are located). Panel tobit estimates with random effects are reported in columns (1) to (3); panel GLM estimates are reported in columns (4) and (5); linear panel estimates with random effects are reported in columns (6) and (7); and pooled OLS estimates with currency fixed effects are reported in columns (8) and (9). The standard errors reported in parentheses in columns (4) to (9) are robust to heteroskedasticity and those in columns (6) to (9) are clustered by time zone (i.e. Asian, European, and US trading hours); *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p≤0.2.

Table 3: IV Estimates –3-D Cable Length Used as Instrument

	(1) Panel tobit	(2) Panel tobit	(3) Panel GLM	(4) Panel GLM	(5) Random effects	(6) Random effects	(7) Pooled OLS	(8) Pooled OLS
Time zone distance	-0.337***	-0.313**	-0.547***	-0.594***	-0.093	-0.139**		
	(0.129)	(0.129)	(0.205)	(0.213)	(0.076)	(0.065)		
Domestic market liquidity	-1.577*	-1.594*	-4.072***	-4.067***	-1.176***	-0.976***	-1.799**	-1.726**
	(0.880)	(0.898)	(1.275)	(1.090)	(0.155)	(0.183)	(0.322)	(0.391)
Capital controls	-0.375+	-0.352+	-1.375*	-1.222+	-0.207	-0.340***	-0.188	-0.320*
	(0.241)	(0.235)	(0.801)	(0.750)	(0.183)	(0.080)	(0.224)	(0.100)
Cables	0.003	-0.047	-0.164	-0.334	0.045	-0.059	0.019	-0.056
	(0.140)	(0.142)	(0.307)	(0.311)	(0.123)	(0.131)	(0.170)	(0.183)
Cables × time zone distance	0.223*	0.231**	0.346+	0.386+	-0.012	0.061	-0.006	0.063
	(0.116)	(0.117)	(0.250)	(0.248)	(0.126)	(0.132)	(0.142)	(0.161)
Cables × domestic market liquidity	1.228+	1.237+	3.285***	3.248***	0.892***	0.689***	1.468**	1.398*
	(0.877)	(0.895)	(1.249)	(1.071)	(0.144)	(0.162)	(0.320)	(0.399)
Cables × capital controls	0.324+	0.309	1.068	0.905	0.107	0.223***	0.126	0.225***
	(0.251)	(0.246)	(0.872)	(0.801)	(0.189)	(0.056)	(0.173)	(0.017)
Trade integration		-0.068		-0.145		-0.069+		0.016
		(0.074)		(0.200)		(0.048)		(0.127)
Financial integration		0.083+		0.132		0.052		-0.009
		(0.063)		(0.189)		(0.043)		(0.095)
Flexible exchange rate regime		0.114**		0.398**		0.094**		0.024
		(0.054)		(0.198)		(0.037)		(0.034)
Carry trades		-0.004*		-0.013		-0.002		-0.002
		(0.002)		(0.014)		(0.002)		(0.003)
Constant	0.290**	0.309**	-0.341	-0.267	0.263***	0.360***		
	(0.145)	(0.155)	(0.324)	(0.375)	(0.099)	(0.127)		
Currency effects	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	252	252	252	238	252	238	252	238
R^2					0.244	0.211	0.939	0.942
ρ	0.833	0.833	0.808		0.734	0.674		

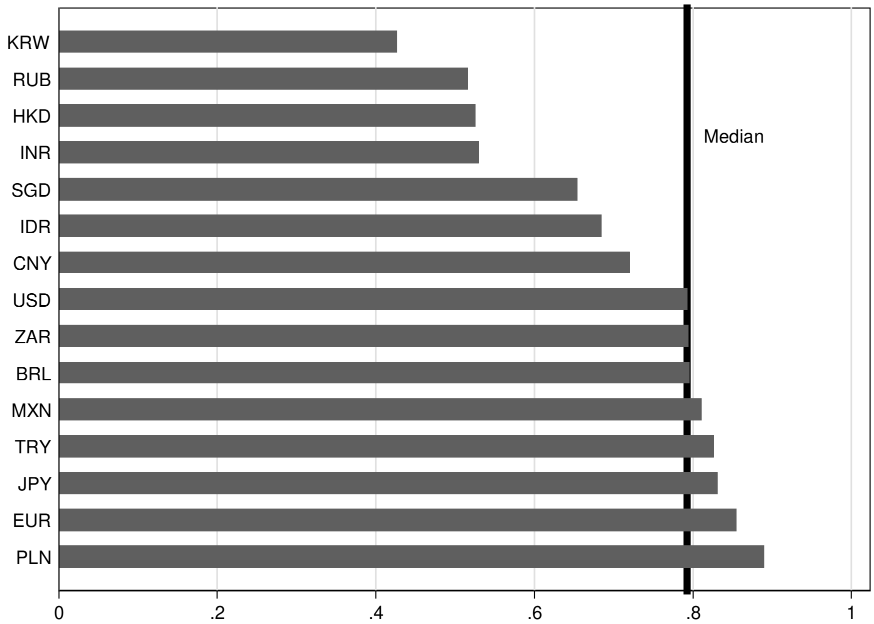
Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the predicted year when countries were connected to the internet backbone, using 3-D cable length as an instrumental variable. Panel tobit estimates with random effects are reported in columns (1) and (2); panel GLM estimates are reported in columns (3) and (4); linear panel estimates with random effects are reported in columns (5) and (6); and pooled OLS estimates with currency fixed effects are reported in columns (7) and (8). The standard errors reported in parentheses in columns (3) to (8) are robust to heteroskedasticity and those in columns (5) to (8) are clustered by time zone (i.e. Asian, European, and US trading hours); *** p<0.01, ** p<0.05, * p<0.1, + p≤0.2.

Table 4: Robustness Checks

	(1) Time trend	(2) Cables × time trend	(3) Geo distance	(4) Log turnover	(5) Total turnover	(6) Capital inflows	(7) Capital outflows	(8) Initial determinants
Time zone distance	-0.405***	-0.401***	-0.058**	-0.450***	-0.476***	-0.453***	-0.432***	-0.375***
	(0.110)	(0.109)	(0.023)	(0.129)	(0.132)	(0.132)	(0.122)	(0.122)
Domestic market liquidity	-1.727**	-2.603***	-1.639*	-2.193**	-1.273**	-1.902**	-1.711**	-0.389***
	(0.834)	(0.972)	(0.868)	(0.907)	(0.622)	(0.845)	(0.832)	(0.091)
Capital controls	-0.469***	-0.577***	-0.265+	-0.280+	-0.289+	-0.232	-0.208+	-0.014
	(0.180)	(0.201)	(0.206)	(0.187)	(0.187)	(0.275)	(0.128)	(0.119)
Cables	-0.332***	-0.282***	-0.064	-0.331***	-0.374***	-0.326***	-0.327***	-0.281**
	(0.101)	(0.103)	(0.094)	(0.115)	(0.123)	(0.120)	(0.113)	(0.111)
Cables × time zone distance	0.333***	0.342***	0.020	0.366***	0.392***	0.390***	0.358***	0.378***
	(0.093)	(0.093)	(0.017)	(0.114)	(0.119)	(0.119)	(0.108)	(0.112)
Cables × domestic market liquidity	1.357+	2.257**	1.265+	1.353+	0.911+	1.538*	1.339+	0.809+
	(0.829)	(0.974)	(0.864)	(0.894)	(0.616)	(0.840)	(0.828)	(0.558)
Cables × capital controls	0.454**	0.561***	0.229	0.230	0.247+	0.164	0.195+	-0.077
	(0.179)	(0.198)	(0.210)	(0.190)	(0.190)	(0.277)	(0.133)	(0.158)
Trade integration	-0.054	-0.103+	-0.116+	-0.071	-0.078	-0.085	-0.074	-0.142**
	(0.074)	(0.077)	(0.072)	(0.073)	(0.073)	(0.073)	(0.072)	(0.069)
Financial integration	0.085+	0.125*	0.115*	0.098+	0.081+	0.099+	0.090+	0.093+
	(0.063)	(0.067)	(0.060)	(0.062)	(0.062)	(0.063)	(0.062)	(0.062)
Flexible exchange rate regime	0.112**	0.119**	0.161***	0.121**	0.125**	0.126**	0.129**	0.124**
	(0.054)	(0.055)	(0.058)	(0.054)	(0.053)	(0.055)	(0.054)	(0.063)
Carry trades	-0.003+	-0.004+	-0.004*	-0.004*	-0.004*	-0.004*	-0.004*	-0.027***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.006)
Constant	0.283**	0.274**	0.210*	0.479***	0.506***	0.477***	0.447***	0.460***
	(0.137)	(0.135)	(0.111)	(0.145)	(0.150)	(0.145)	(0.141)	(0.136)
Currency effects	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	NO	NO	YES	YES	YES	YES	YES	YES
Observations	238	238	238	238	238	238	238	203
ρ	0.792	0.782	0.739	0.822	0.821	0.799	0.802	0.766

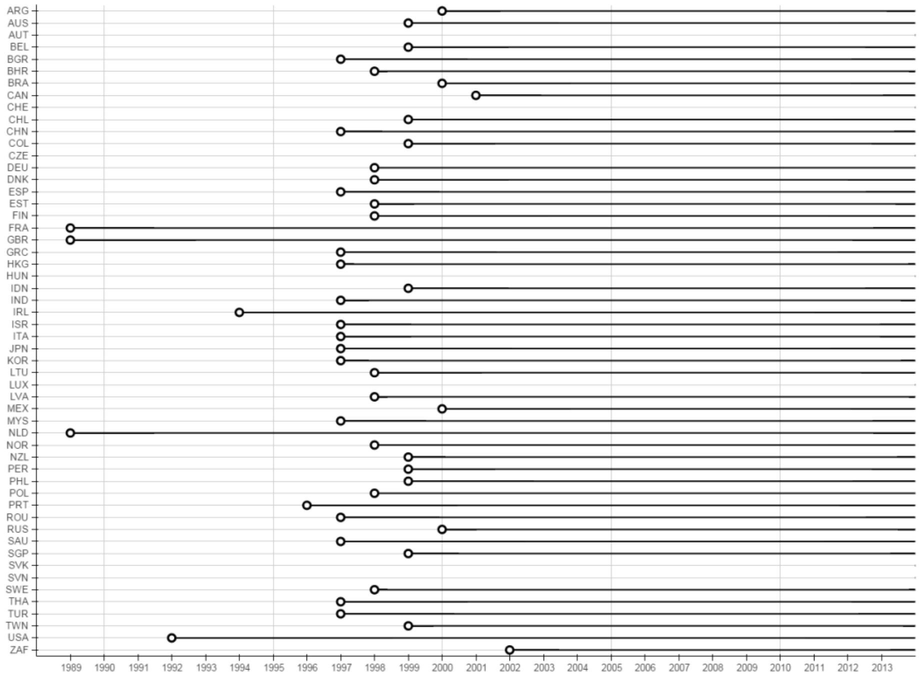
Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effect of both point-to-point and via third countries submarine fiber-optic cable connections to the U.K., U.S. or Japan (i.e. the three countries where the matching servers of EBS/Reuters for electronic trading are located) and a time trend in lieu of time fixed effects (in column 1); cable connections interacted with a time trend (in column 2); geographical distance in lieu of the time difference to the U.K., U.S. or Japan (in column 3); the log of FX turnover rather than its level (in column 4); total FX turnover rather than FX turnover net of domestic currency turnover (in column 5); restrictions on capital inflows rather than restrictions on all flows (in column 6); restrictions on capital outflows (in column 7); initial values of the standard determinants of the geography of foreign exchange trading (in column 8). *** p<0.01, ** p<0.05, * p<0.1, + p<0.2.

Figure 1: Offshore Foreign Exchange Trading in 2013
– Breakdown for Selected Currencies



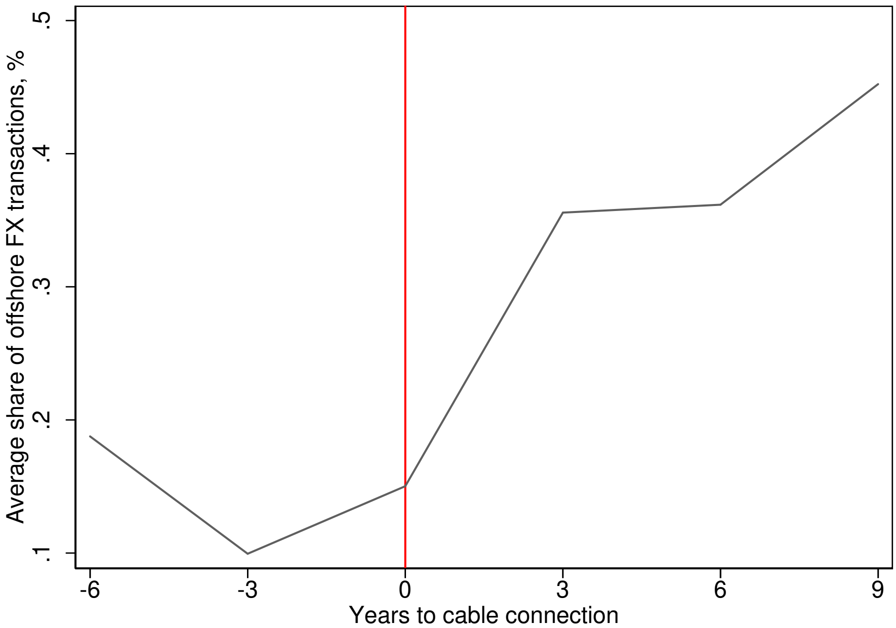
Notes. This figure shows the shares of foreign exchange trading occurring offshore for the same units as in McCauley and Scatigna (2011) and Ehlers and Packer (2013). The thick black line is the (unweighted) median of all individual currency shares (including those not reported in the figure).

Figure 2: Year of First Connection to the UK, US or Japan via a Submarine Fiber-Optic Cable



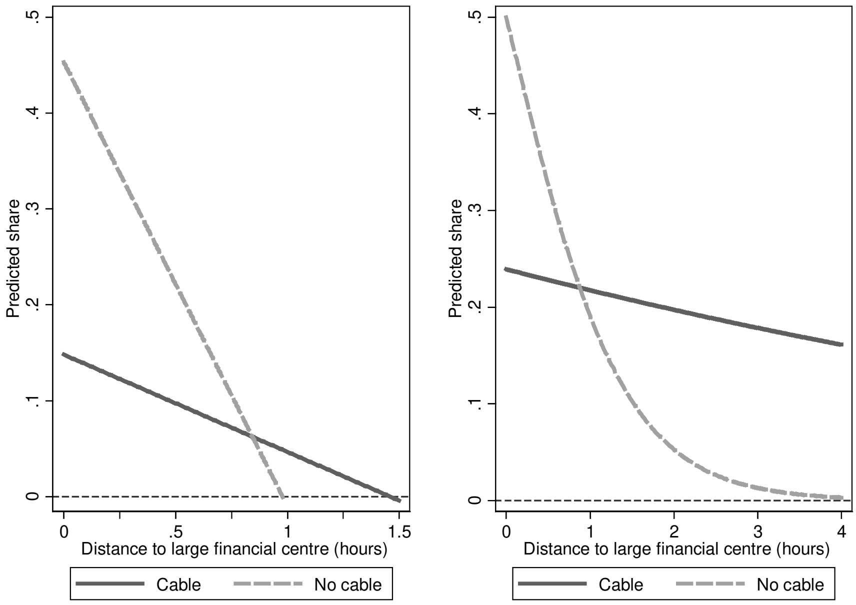
Notes. This figure shows the year when the countries issuing the 55 currencies of our sample were first connected (point-to-point or via third countries) via a submarine fiber-optic cable to the U.K., the U.S. or Japan (i.e. the three countries where the matching servers of EBS/Reuters for electronic foreign exchange trading are located).

Figure 3: Event Study of the Effect of Cable Connections



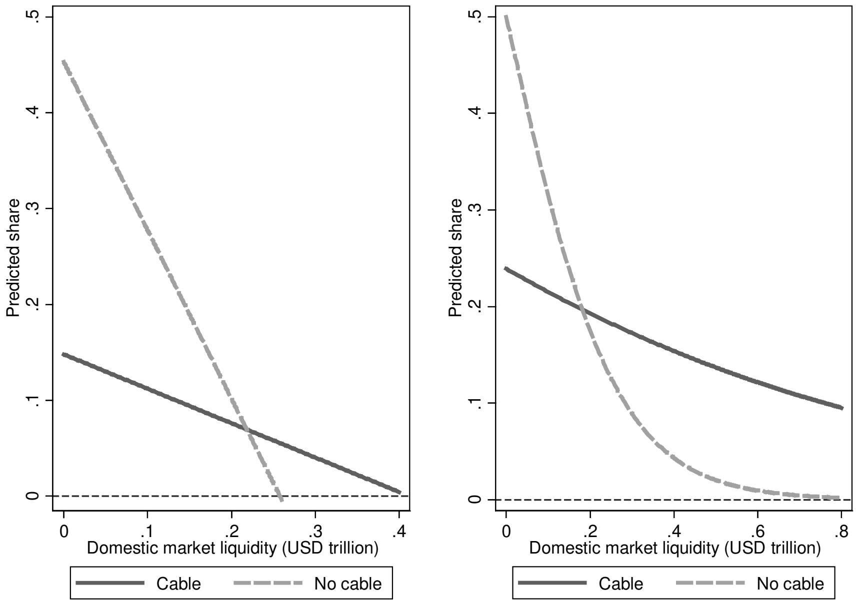
Notes: This figure shows the average share of offshore foreign exchange transactions in the economies of the sample in 3-year intervals prior and after connection to the internet backbone (the length of the intervals corresponds to the number of years between waves of BIS triennial surveys).

Figure 4: Impact of Submarine Fiber-Optic Cable Connection
– Information Asymmetries



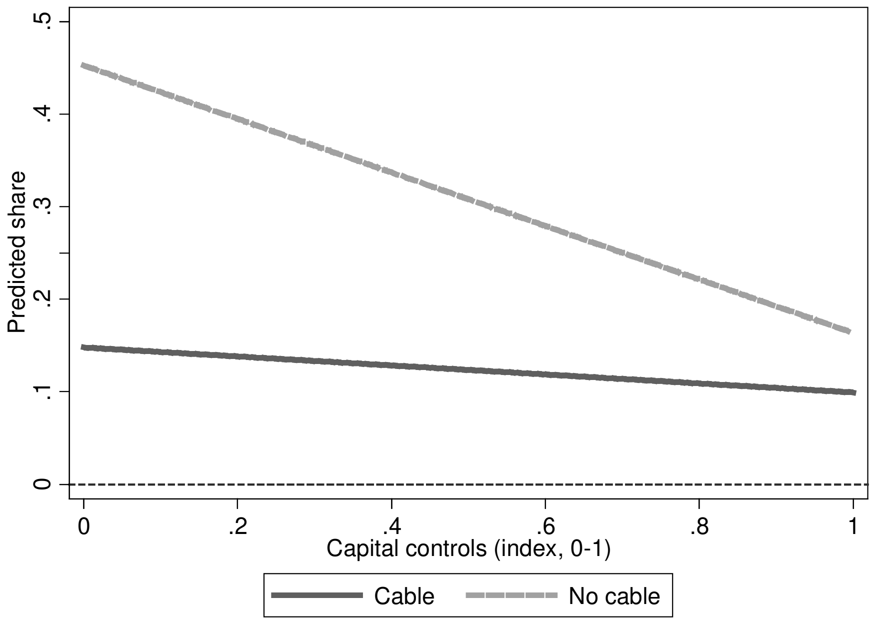
Notes. This figure shows the predicted share of offshore FX trading conditional on the extent of information asymmetries, while other spatial determinants are set to zero with (solid line) and without (dashed line) cable connection. The left-hand side figure is based on the tobit estimates reported in column 2 of Table 2; the right-hand side figure is based on the panel GLM estimates reported in column 4 of Table 2.

Figure 5: Impact of Submarine Fiber-Optic Cable Connection
– Domestic Market Liquidity



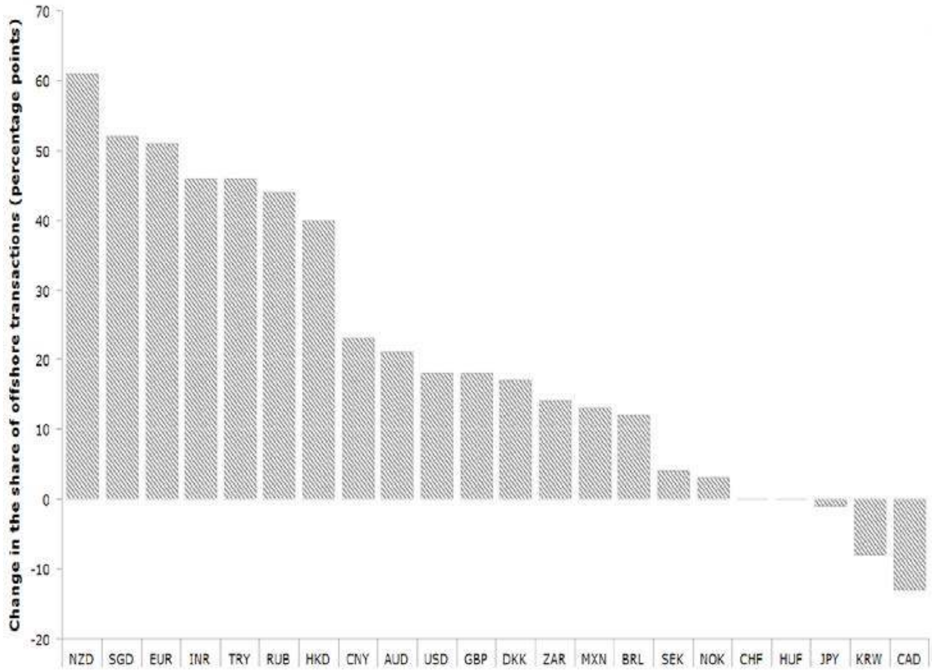
Notes. This figure shows the predicted share of offshore FX trading conditional on the extent of domestic market liquidity, while other spatial determinants are set to zero, with (solid line) and without (dashed line) cable connection. The left-hand side figure is based on the tobit estimates reported in column 2 of Table 2; the right-hand side figure is based on the panel GLM estimates reported in column 4 of Table 2.

Figure 6: Impact of Submarine Fiber-Optic Cable Connection
– Capital Controls



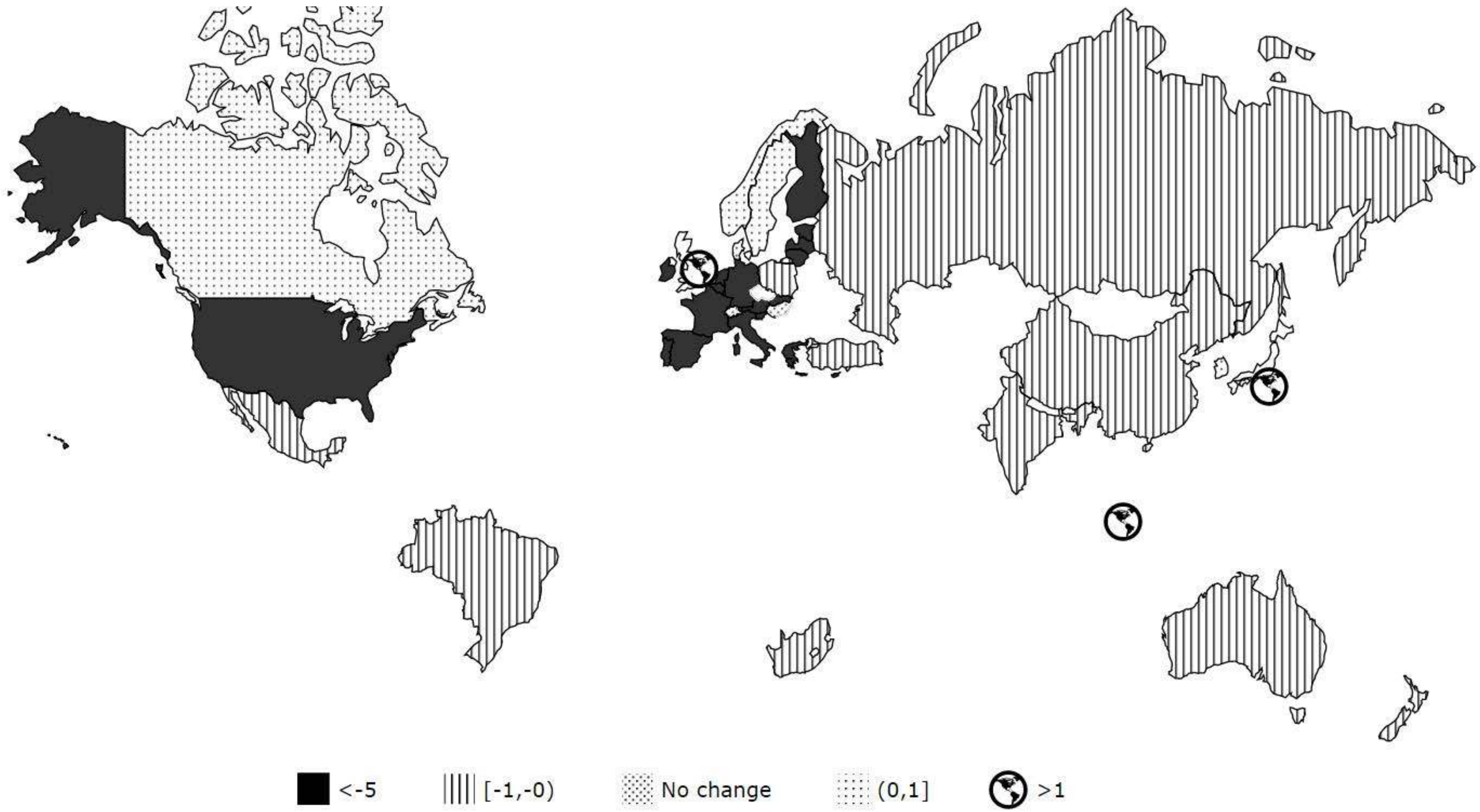
Notes. This figure shows the predicted share of offshore FX trading conditional on the extent of capital controls, while other spatial determinants are set to zero, with (solid line) and without (dashed line) cable connection. The figure is based on the tobit estimates reported in column 2 of Table 2.

Figure 7: Net Effect of Cable Connections on Offshore FX trading



Notes. This figure shows the change (in percentage points) in the share of foreign exchange transactions occurring offshore by currency if countries which issue the currencies in question are connected to a submarine fiber-optic cable relative to a counterfactual situation when they are not. These estimates are based on data for 2013 and the GLM results reported in column 4 of Table 2.

Figure 8: Distributional Effects of Cable Connections Across Financial Centers



Notes. This map shows the change in percentage points in the share of global foreign exchange transactions undertaken in the countries of our sample if they are connected to a submarine fiber-optic cable relative to a counterfactual in which they are not. The estimates are based on data for 2013 and the panel GLM results reported in column 4 of Table 2. They are based on the assumption that net gains in offshore trading (i.e. the balance between the direct and indirect effects of cable connections) are allocated across connected countries proportionately to their actual share of global foreign exchange transactions in 2013.

APPENDICES – FOR ONLINE PUBLICATION

A PRIMER ON ELECTRONIC FOREIGN EXHANGE TRADING AND SUBMARINE FIBER-OPTIC CABLES

The foreign exchange market has been transformed since the late 1980s by the advent of electronic broking and trading, reflecting the availability of less expensive and more efficient information and communications technology. Electronic trading dominates today's foreign exchange market, with a share above 50% for all customer segments and availability for instruments and investors globally.[68] By comparison, in 2001 only half of turnover in the major currencies was conducted through electronic brokers, up from 40% in 1998 and roughly 10% in 1995.[69]

Electronic brokers were introduced in the inter-dealer foreign exchange market as early as in 1992. Two platforms, EBS and Thomson Reuters, dominated this market segment. They reduced transaction costs relative to traditional means of dealing, like voice trading. In voice trading, a dealer would contact other dealers to obtain information on prices available in the market and, presumably, complete the deal at the best price offered. With the advent of electronic brokers, dealers could immediately learn via a computer terminal the best available price and complete the transaction then and there.

In contrast to the inter-dealer market, which rapidly migrated to electronic platforms, as late as 2000 the main trading channel for market participants other than dealers remained direct contacts with dealers over the phone. As a result, the turn-of-the-century foreign exchange market was still segmented between the inter-dealer market (which was heavily electronic) and the retail-dealer market (which was not). This segmentation was then reduced in the course of the subsequent decade. A multi-bank trading system providing customers with competing quotes from different dealers on a single page (Currenex) was launched in 1999. As other multi-bank platforms such as FXall and Hotspot followed, transparency rose and transactions costs fell further. Between 2001 and 2006 large dealers launched proprietary single-bank trading systems for their customers; examples of such systems include Barclays' BARX, Deutsche

[68] See Rime and Schrimpf (2013), p. 34.

[69] See Galati (2001), p. 39 and BIS (2001). The share of turnover in other currencies was far less. The challenges created by the rise of electronic trading attracted markets and policy-makers' attention as early as the 1990s (see e.g. CGFS 2001).

Bank's Autobahn and Citigroup's Velocity. And starting around 2005, EBS and Thomson Reuters, which previously offered brokerage services to dealers only, opened up to hedge funds and other traders. Their platforms consequently evolved into leading venues for high-frequency trading firms.

A key factor underlying the rise of electronic trading in the foreign exchange market was the internet and its backbone, i.e. the network of some 350 submarine fiber-optic cables that connect computers around the world. An important feature of this network, highly relevant to our analysis, is that it was not laid for purposes related to electronic foreign exchange trading. Establishing this fact requires us to review some of the relevant history.[70]

The first submarine cables were laid to carry telegraph signals. Samuel Morse (of Morse Code fame) submerged a copper cable covered by tarred hemp and rubber in New York Harbor in 1842 and demonstrated the feasibility of transmitting telegraphic signals. Cables covered with gutta-percha (gum from gutta-percha trees) connecting Great Britain with the European continent were then laid starting in the 1850s. A successful transatlantic cable followed, after eight years of failed attempts, in 1866. That cable proved quickly its usefulness for trading and financial information. The US dollar-sterling exchange rate hence became colloquially named "cable" after its primary Atlantic transmission medium. Other copper cables (more precisely, cables of copper wire surrounded by rubber or gutta-percha, in turn surrounded by an outer layer of iron or steel wire) subsequently connected a growing range of locations.

Early submarine cables were subject to problems of reliability and capacity. In the absence of repeater amplifiers, high voltages were required to transmit signals over long distances, creating distortion, limiting carrying capacity and heightening the risk of short-circuiting. Thick, costly copper wires were required to slow signal loss. The physical cables were often weakened or disrupted by storms and damaged by currents and fishing trawlers.

Only in the 1890s did the science of transmitting higher frequencies, essential for data and voice, begin to be established. Another breakthrough essential for long-distance telephonic communication was development of a practical vacuum-tube-based repeater amplifier in the opening years of the 20th century. Commercialization was then

[70] A detailed account of the early history of submarine cables is Wenzlhuemer (2013).

delayed by the two world wars and the Great Depression. The first modern submarine cable, TAT-1 (Transatlantic No. 1), a coaxial cable insulated using polyethylene (rather than gutta-percha) and utilizing vacuum tubes as repeaters, was finally laid starting in 1955. TAT-1 connected Oban, Scotland with Clarenville, Newfoundland. It was underwritten by AT&T, the Canadian Overseas Telecommunications Corporation, and the UK General Post Office. When inaugurated on September 25, 1956, it had 36 separate channels, enabling it to carry 35 simultaneous telephone calls along with 22 telegraph lines on the 36th channel. The 1960s saw the development of coaxial cables of somewhat greater reliability and carrying capacity that operated with narrower bandwidths and utilized transistors rather than vacuum tubes as repeaters.[71]

Coaxial cables were superseded in the 1980s by fiber-optic cables.[72] Fiber-optic cable connections increase bandwidth (i.e. the amount of data that can be put through per unit of time) enormously relative to coaxial cables.[73] The first submarine fiber-optic cable, TAT-8, entered service in December 1988. Financed by a consortium led by AT&T, France Télécom (now Orange) and British Telecom, TAT-8 had a branching unit underwater, off the coast of Great Britain, enabling it to connect to both the US and France. It had a capacity of 40,000 circuits, allowing it to carry as many as 40,000 simultaneous telephone calls or similar communications, a tenfold increase relative to coaxial cables.

Initially, this cable, not unlike its 1850s predecessor, had reliability problems. The absence of electrical interference shielding caused electrical current it carried to attract sharks, which attacked the cable. (Sharks are subject to electroreception, the biological ability to perceive electric current, which sets off feeding frenzies.) Subsequent cables, starting with PTAT-1 in 1989, were fitted with shark shielding, enhancing reliability. This is the point in time that we would date the initial availability

[71] In coaxial cables, the copper or copper-plated steel wire is surrounded by an insulating layer which is in turn enclosed by a metallic shield.

[72] Fiber-optic cables are made by stretching glass (or silica) to roughly the diameter of a human hair.

[73] Fiber optics also reduce losses in signal transmission over long distances. They transfer data at a speed of 180,000-200,000 kilometers per second (i.e. the speed of light in glass), resulting in latency per kilometer of 5 to 5.5 microseconds (a 10 to 11 millisecond delay for a roundtrip of 1,000 kilometers). Coaxial (copper) cables carry signal at a speed close to that of light in a vacuum. However, copper cables are affected by electromagnetic interference and are prone to higher rates of loss over long distances. For short distances, copper cables can be the first choices, because of their low cost, while over long distances fiber optic cables are more reliable but costlier.

of the information and communication technology needed to support long-distance electronic foreign exchange trading.

PTAT-1 was also the first fiber optic submarine cable to be financed entirely privately. It was underwritten by a US company, TelOptik, and by Cable and Wireless plc in the U.K, which built it – importantly – to carry telephonic traffic in competition with AT&T and British Telecom.

By 2006, 99 per cent of international communications traffic was carried by submarine cables, while the remainder was carried by satellite. Fiber-optic cables remain the principal conduit for data transmission for the internet in general and electronic trading of foreign exchange in particular, because submarine fiber-optic cables still have lower latency, larger bandwidth and reliability performance than satellite transmission. That fiber-optic cables have advantages along these dimensions is evident from the example in Table A1. Relative to copper, fiber typically offers a thousand times as much bandwidth over distances a hundred times further. It is hence a hundred times cheaper than copper (per voice channel and kilometer) even if it costs a thousand times as much to build.

Might earlier telephonic cables, before the advent of fiber optics, have had a similar effect on the location of foreign exchange trading? This is doubtful, for reasons of bandwidth. Electronic trading developed because market participants gained access to broadband internet connections allowing them to transmit large amounts of data and book large numbers of transactions on a handful of large electronic platforms. Such use was not possible with earlier telephonic cables, which transmitted data less reliably and in more limited amounts.[74]

[74] Electronic trading developed because market infrastructure (EBS and Thomson Reuters servers) was now able to handle large numbers of simultaneous orders. Such infrastructure was non-existent prior to the fiber-optic era, because it requires large data storage capacity and fast computing, which were beyond technical capabilities in the earlier period.

Table A1: Comparative Bandwidth Performance of Fiber vs. Coaxial Cables

	Distance	Bandwidth	Voice channels
Copper	2.5 km	1.5 Mb/s	24
Fiber	200 km	2.5+ Gb/s	32,000+

Source: "Copper or Fiber? What's the Real Story for Communications Cabling?" The Fiber-Optic Association, Inc. http://www.thefoa.org/tech/fo-or-cu.htm, accessed June 2nd, 2016.

Table A2: Ownership of the Submarine Fiber-Optic Cables Laid Between 1989 and 2002

a. Point-to-Point Connections to the U.K. (London)

Cable name	*Year*	*Length (km)*	*id*	*Owners*
	1989	35	1387	BT
UK-France 3	1989	155	1314	BT, Orange, Vodafone
Farland North	1989	150	1819	BT
BT-MT-1	1990	80	1752	BT, Manx Telecom
Lanis-2	1992	67	1751	Vodafone
Lanis-1	1992	113	1616	Vodafone
Lanis-3	1992	122	1834	Vodafone
Swansea-Brean	1993	97	1835	Vodafone
Scotland-Northern Ireland 2	1993	82	1614	BT
Swansea-Brean	1993	97	1835	Vodafone
Celtic	1994	275	1054	BT, eircom, Orange
UK-Netherlands 14	1996	208	1365	BT, KPN, Vodafone
Ulysses	1997	250	1343	Verizon
FLAG Europe-Asia (FEA)	1997	28000	1027	Global Cloud Xchange
Ulysses	1997	250	1343	Verizon
Atlantic Crossing-1 (AC-1)	1998	14301	1143	Level 3
SeaMeWe-3	1999	39000	1031	Orange, BT, KDDI, SingTel, Telecom Italia Sparkle, Telekom Malaysia, OTEGLOBE, AT&T, Belgacom, Communications Authority of Thailand, China Telecom, Deutsche Telekom, Etisalat, Telecom Egypt, CTM, PT Indonesia Satellite Corp., Jabatan Telecom Brunei, KT, Portugal Telecom, Maroc Telecom, PLDT, Saudi Telecom, Sri Lanka Telecom, Turk Telekom, Tata Communications, Chunghwa Telecom, Verizon, KPN, Telekom Austria, SingTel Optus, Telstra, Vietnam Telecom International, Omantel, PCCW, Pakistan Telecommunications Company Ltd., Cyta, eircom, LG Uplus, Softbank Telecom, Telkom South Africa, Rostelecom, Orange Polska, SingTel Optus, Telecom Argentina, Myanmar Post and Telecommunication, Sprint, Vocus Communications, Djibouti Telecom, Embratel, Vodafone
Sirius North	1999	147	1754	Virgin Media Business
Solas	1999	232	1205	eircom, Vodafone
Concerto	1999	550	1538	Interoute
Pan European Crossing (UK-Belgium)	1999	117	1539	Level 3
Tampnet Offshore FOC Network	1999	1751	1203	Tampnet
Sirius South	1999	219	1092	Virgin Media Business
Circe South	1999	115	1323	VTLWavenet, euNetworks
Sirius North	1999	147	1754	Virgin Media Business
Circe North	1999	203	1137	VTLWavenet, euNetworks
ESAT-1	1999	261	1223	Esat BT
Pan European Crossing (UK-Ireland)	2000	495	1547	Level 3
Tangerine	2000	112	1324	Level 3
ESAT-2	2000	245	1224	Esat BT
Yellow	2000	7001	1081	Level 3
Hibernia Atlantic	2001	12200	1080	Hibernia Networks
Tata TGN-Atlantic	2001	13000	1149	Tata Communications
FLAG Atlantic-1 (FA-1)	2001	14500	1028	Global Cloud Xchange
TAT-14	2001	15295	1043	BT, Verizon, Deutsche Telekom, Orange, Sprint, TeliaSonera, Level 3, KPN, Telenor, Etisalat, OTEGLOBE, SingTel, KDDI, Softbank Telecom, Zayo Group, Portugal Telecom, Slovak Telekom, TDC, Telus, Tata Communications, Telefonica, AT&T, Belgacom, Elisa Corporation, Cyta, Rostelecom, Vodafone
Hibernia Atlantic	2001	12200	1080	Hibernia Networks
Tata TGN-Western Europe	2002	3578	1173	Tata Communications

b. Point-to-Point Connections to the U.S. (New York)

Cable name	Year	Length (km)	id	Owners
Taino-Carib	1992	186	1229	AT&T, Embratel, Telecom Argentina, Orange, CANTV, Columbus Networks, Telecom Italia Sparkle
HICS (Hawaii Inter-Island Cable System)	1994	479.081	1455	Hawaiian Telcom
Columbus-II b	1994	2068	1643	n.a.
HIFN (Hawaii Island Fibre Network)	1997	529	1456	TW Telecom, Hawaiian Telcom
Antillas 1	1997	650	1227	AT&T, Verizon, Sprint, Tata Communications, Orange, Columbus Networks, Telecom Italia Sparkle, Embratel
HIFN (Hawaii Island Fibre Network)	1997	529	1456	TW Telecom, Hawaiian Telcom
Bahamas 2	1997	470	1069	AT&T, Telefonica, Verizon
Atlantic Crossing-1 (AC-1)	1998	14301	1143	Level 3
Pacific Crossing-1 (PC-1)	1999	20900	1007	NTT
NorthStar	1999	3229	1166	Alaska Communications Systems Group
Pacific Crossing-1 (PC-1)	1999	20900	1007	NTT
Pan American (PAN-AM)	1999	7050	1073	AT&T, Telefonica del Peru, Softbank Telecom, Telecom Italia Sparkle, Sprint, CANTV, Tata Communications, TelefÃ³nica de Argentina (Speedy), Telstra, Verizon, Entel Chile, Telecom Argentina, Telconet, Cable & Wireless Communications, Corporacion Nacional de Telecommunicaciones, Columbus Networks, Embratel
Alaska United East	1999	3751	1168	GCI
Columbus-III	1999	9833	1046	Telecom Italia Sparkle, AT&T, Verizon, Telefonica, Portugal Telecom, CANTV, Tata Communications, Ukrtelecom, Telkom South Africa, Telecom Argentina, Cable & Wireless Communications, Embratel
GlobeNet	2000	23500	1076	BTG Pactual
South American Crossing (SAC)/Latin American Nautilus (LAN)	2000	20000	1084	Level 3, Telecom Italia Sparkle
Southern Cross Cable Network (SCCN)	2000	30500	1009	Spark New Zealand, SingTel Optus, Verizon
GlobeNet	2000	23500	1076	BTG Pactual
Maya-1	2000	4400	1071	Cable & Wireless Communications, Verizon, Tata Communications, AT&T, Sprint, Hondutel, CANTV, Telefonica, BT, Orbitel, Telecom Italia Sparkle, Columbus Networks, Entel Chile, Telmex, Embratel, ETB, Alestra
Mid-Atlantic Crossing (MAC)	2000	7500	1070	Level 3
China-U.S. Cable Network (CHUS)	2000	30476	1146	Verizon, AT&T, KDDI, Tata Communications, China Telecom, Chunghwa Telecom, KT, NTT, Level 3, SingTel, Sprint, Telekom Malaysia, Spark New Zealand, Telstra, PCCW, LG Uplus, Softbank Telecom, Rostelecom, SingTel Optus, Orange, PLDT
Yellow	2000	7001	1081	Level 3
name	2000	10000	1072	Level 3
Southern Cross Cable Network (SCCN)	2000	30500	1009	Spark New Zealand, SingTel Optus, Verizon
Americas-II	2000	8373	1148	Embratel, AT&T, Verizon, Sprint, CANTV, Tata Communications, Level 3, Centennial of Puerto Rico, Corporacion Nacional de Telecommunicaciones, Telecom Argentina, Orange, Portugal Telecom, Columbus Networks, Telecom Italia Sparkle, Entel Chile
Southern Cross Cable Network (SCCN)	2000	30500	1009	Spark New Zealand, SingTel Optus, Verizon
Mid-Atlantic Crossing (MAC)	2000	7500	1070	Level 3
Japan-U.S. Cable Network (JUS)	2001	22682	1010	Verizon, AT&T, BT, Sprint, CenturyLink, KDDI, NTT, Chunghwa Telecom, Tata Communications, SingTel, Telekom Malaysia, Softbank Telecom, Orange, Level 3, SK Broadband, KT, China Telecom, China Unicom, LG Uplus, New World Telecom, Starhub, PCCW, Telstra, Vodafone, PLDT
FLAG Atlantic-1 (FA-1)	2001	14500	1028	Global Cloud Xchange
Hibernia Atlantic	2001	12200	1080	Hibernia Networks
Bahamas Internet Cable System (BICS)	2001	1100	1232	Caribbean Crossings
TAT-14	2001	15295	1043	BT, Verizon, Deutsche Telekom, Orange, Sprint, TeliaSonera, Level 3, KPN, Telenor, Etisalat, OTEGLOBE, SingTel, KDDI, Softbank Telecom, Zayo Group, Portugal Telecom, Slovak Telekom, TDC, Telus, Tata Communications, Telefonica, AT&T, Belgacom, Elisa Corporation, Cyta, Rostelecom, Vodafone
South America-1 (SAm-1)	2001	25000	1083	Telefonica
Japan-U.S. Cable Network (JUS)	2001	22682	1010	Verizon, AT&T, BT, Sprint, CenturyLink, KDDI, NTT, Chunghwa Telecom, Tata Communications, SingTel, Telekom Malaysia, Softbank Telecom, Orange, Level 3, SK Broadband, KT, China Telecom, China Unicom, LG Uplus, New World Telecom, Starhub, PCCW, Telstra, Vodafone, PLDT
ARCOS	2001	8600	1078	Columbus Networks, Axtel, CANTV, Codetel, Hondutel, Belize Telemedia, Enitel, AT&T, Alestra, Verizon, RACSA, United Telecommunication Services (UTS), Telecarrier, Tricom USA, Telecomunicaciones Ultramarinas de Puerto Rico, Internexa, Orbinet Overseas, Telepuerto San Isidro, Bahamas Telecommunications Company
Tata TGN-Atlantic	2001	13000	1149	Tata Communications
TAT-14	2001	15295	1043	BT, Verizon, Deutsche Telekom, Orange, Sprint, TeliaSonera, Level 3, KPN, Telenor, Etisalat, OTEGLOBE, SingTel, KDDI, Softbank Telecom, Zayo Group, Portugal Telecom, Slovak Telekom, TDC, Telus, Tata Communications, Telefonica, AT&T, Belgacom, Elisa Corporation, Cyta, Rostelecom, Vodafone
South America-1 (SAm-1)	2001	25000	1083	Telefonica
Tata TGN-Pacific	2002	22300	1155	Tata Communications

a. Point-to-Point Connections to Japan (Tokyo)

Cable name	*Year*	*Length (km)*	*id*	*Owners*
FLAG Europe-Asia (FEA)	1997	28000	1027	Global Cloud Xchange
Pacific Crossing-1 (PC-1)	1999	20900	1007	NTT
SeaMeWe-3	1999	39000	1031	Orange, BT, KDDI, SingTel, Telecom Italia Sparkle, Telekom Malaysia, OTEGLOBE, AT&T, Belgacom, Communications Authority of Thailand, China Telecom, Deutsche Telekom, Etisalat, Telecom Egypt, CTM, PT Indonesia Satellite Corp., Jabatan Telecom Brunei, KT, Portugal Telecom, Maroc Telecom, PLDT, Saudi Telecom, Sri Lanka Telecom, Turk Telekom, Tata Communications, Chunghwa Telecom, Verizon, KPN, Telekom Austria, SingTel Optus, Telstra, Vietnam Telecom International, Omantel, PCCW, Pakistan Telecommunications Company Ltd., Cyta, eircom, LG Uplus, Softbank Telecom, Telkom South Africa, Rostelecom, Orange Polska, SingTel Optus, Telecom Argentina, Myanmar Post and Telecommunication, Sprint, Vocus Communications, Djibouti Telecom, Embratel, Vodafone
Pacific Crossing-1 (PC-1)	1999	20900	1007	NTT
China-U.S. Cable Network (CHUS)	2000	30476	1146	Verizon, AT&T, KDDI, Tata Communications, China Telecom, Chunghwa Telecom, KT, NTT, Level 3, SingTel, Sprint, Telekom Malaysia, Spark New Zealand, Telstra, PCCW, LG Uplus, Softbank Telecom, Rostelecom, SingTel Optus, Orange, PLDT
Australia-Japan Cable (AJC)	2001	12700	1102	Softbank Telecom, NTT, Telstra, Verizon, AT&T
APCN-2	2001	19000	1049	SingTel, Verizon, KDDI, Chunghwa Telecom, AT&T, BT, Orange, Softbank Telecom, NTT, Tata Communications, Telekom Malaysia, Starhub, PLDT, China Unicom, KT, SingTel Optus, Telstra, PCCW, China Telecom, LG Uplus, New World Telecom, Vodafone
Japan-U.S. Cable Network (JUS)	2001	22682	1010	Verizon, AT&T, BT, Sprint, CenturyLink, KDDI, NTT, Chunghwa Telecom, Tata Communications, SingTel, Telekom Malaysia, Softbank Telecom, Orange, Level 3, SK Broadband, KT, China Telecom, China Unicom, LG Uplus, New World Telecom, Starhub, PCCW, Telstra, Vodafone, PLDT
FLAG North Asia Loop/REACH North Asia Loop	2001	9504	1150	Global Cloud Xchange, PCCW, Telstra
Japan-U.S. Cable Network (JUS)	2001	22682	1010	Verizon, AT&T, BT, Sprint, CenturyLink, KDDI, NTT, Chunghwa Telecom, Tata Communications, SingTel, Telekom Malaysia, Softbank Telecom, Orange, Level 3, SK Broadband, KT, China Telecom, China Unicom, LG Uplus, New World Telecom, Starhub, PCCW, Telstra, Vodafone, PLDT
APCN-2	2001	19000	1049	SingTel, Verizon, KDDI, Chunghwa Telecom, AT&T, BT, Orange, Softbank Telecom, NTT, Tata Communications, Telekom Malaysia, Starhub, PLDT, China Unicom, KT, SingTel Optus, Telstra, PCCW, China Telecom, LG Uplus, New World Telecom, Vodafone
EAC-C2C	2002	36500	1592	Pacnet
Korea-Japan Cable Network (KJCN)	2002	500	1231	QTNet, KT, Softbank Telecom, NTT
Tata TGN-Pacific	2002	22300	1155	Tata Communications

Sources: Authors' compilation based on the data made available by TeleGeography at the following url: https://github.com/telegeography/www.submarinecablemap.com.

Table A3: First-stage Estimates

	(1)	(2)	(3)	(4)
3D-cable length	0.995***		1.198***	1.692***
	(0.286)		(0.396)	(0.552)
Ruggedness		0.014+	-0.008	0.101
		(0.008)	(0.010)	(0.086)
Ruggedness × 3D-cable length				-0.014
				(0.011)
Constant	1,989.825***	1,996.856***	1,988.694***	1,985.272***
	(2.288)	(0.616)	(2.754)	(3.834)
Observations	44	44	44	44
R^2	0.224	0.063	0.234	0.264
F-statistic	12.09	2.811	6.261	4.778

Notes. The table reports the first-stage estimates of IV strategy where the actual year when countries were connected to the internet backbone is regressed individually on 3-D cable length (column 1), ruggedness of the seabed (column 2), these two variables jointly (column 3) and their interaction (column 4). The standard errors are reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p≤0.2.

Table A4: Estimates Obtained on Alternative Sample Periods

	(1)	(2)	(3)	(4)	(5)	(6)
	1995-2010		1995-2007		1995-2004	
Time zone distance	-0.485***	-0.404***	-0.505***	-0.415***	-0.505***	-0.415***
	(0.136)	(0.143)	(0.152)	(0.152)	(0.152)	(0.152)
Domestic market liquidity	-1.626*	0.720	-1.150	0.726	-1.150	0.726
	(0.894)	(1.223)	(1.242)	(1.586)	(1.242)	(1.586)
Capital controls	-0.285+	-0.563**	-0.287	-0.605**	-0.287	-0.605**
	(0.213)	(0.267)	(0.252)	(0.295)	(0.252)	(0.295)
Cables	-0.286**	0.070	-0.260*	0.034	-0.260*	0.034
	(0.121)	(0.141)	(0.137)	(0.155)	(0.137)	(0.155)
Cables × time zone distance	0.370***	0.349***	0.381***	0.355***	0.381***	0.355***
	(0.120)	(0.128)	(0.136)	(0.137)	(0.136)	(0.137)
Cables × domestic market liquidity	1.168+	-0.543	0.678	-0.364	0.678	-0.364
	(0.887)	(1.229)	(1.231)	(1.597)	(1.231)	(1.597)
Cables × capital controls	0.176	0.480*	0.105	0.469+	0.105	0.469+
	(0.215)	(0.270)	(0.254)	(0.301)	(0.254)	(0.301)
Constant	0.446***	0.336**	0.419***	0.325*	0.419***	0.325*
	(0.141)	(0.165)	(0.156)	(0.176)	(0.156)	(0.176)
Currency effects	YES	YES	YES	YES	YES	YES
Time effects	YES	NO	YES	NO	YES	NO
Observations	214	214	176	176	176	176
ρ	0.836	0.692	0.829	0.695	0.829	0.695

Notes. The table reports panel tobit estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country. The estimates are obtained on alternative sample periods, namely: 1995-2010 in columns (1) and (2); 1995-2007 in columns (3) and (4); and 1995-2004 in columns (5) and (6). *** $p<0.01$, ** $p<0.05$, * $p<0.1$, $^{+}$ $p<0.2$.

Table A5: Estimates with a Balanced Sample

	(1) Full sample	(2) Balanced sample
Time zone distance	-0.430***	-0.429***
	(0.126)	(0.153)
Domestic market liquidity	-1.784**	-1.624**
	(0.831)	(0.772)
Capital controls	-0.288+	-0.083
	(0.190)	(0.330)
Cables	-0.332***	-0.251**
	(0.115)	(0.106)
Cables × time zone distance	0.361***	0.475***
	(0.113)	(0.121)
Cables × domestic market liquidity	1.415*	1.423*
	(0.827)	(0.768)
Cables × capital controls	0.243+	-0.033
	(0.192)	(0.245)
Constant	0.463***	0.606***
	(0.142)	(0.170)
Observations	238	119

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country. The basic panel tobit estimates with random effects are reported in column (1) and estimates with a balanced sample restricted to currencies reporting information on trading location since 1995 are reported in column (2). Standard errors reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1, + p<0.2.

Table A6: Testing for Structural Change

	(1) Basic estimates	(2) Cables × time trend	(3) Break in 2001	(4) Break in 2004	(5) Break in 2007
Time zone distance	-0.430***	-0.401***	-0.434***	-0.416***	-0.421***
	(0.126)	(0.109)	(0.126)	(0.121)	(0.122)
Domestic market liquidity	-1.784**	-2.603***	-2.444***	-2.848***	-2.107**
	(0.831)	(0.972)	(0.931)	(1.071)	(0.904)
Capital controls	-0.288+	-0.577***	-0.315+	-0.437**	-0.338*
	(0.190)	(0.201)	(0.195)	(0.215)	(0.195)
Cables	-0.332***	-0.282***	-0.287**	-0.330***	-0.313***
	(0.115)	(0.103)	(0.121)	(0.118)	(0.114)
Cables × time zone distance	0.361***	0.342***	0.310***	0.308***	0.327***
	(0.113)	(0.093)	(0.118)	(0.110)	(0.110)
Cables × domestic market liquidity	1.415*	2.257**	2.441**	2.907**	1.871**
	(0.827)	(0.974)	(1.002)	(1.129)	(0.913)
Cables × capital controls	0.243+	0.561***	0.230	0.348+	0.272+
	(0.192)	(0.198)	(0.208)	(0.216)	(0.198)
Cables × break dummy			-0.260**	-0.300**	-0.208**
			(0.110)	(0.121)	(0.106)
Cables × time zone distance × break dummy			0.085*	0.092**	0.079**
			(0.048)	(0.040)	(0.034)
Cables × domestic market liquidity × break dummy			-0.251	-0.274	-0.047
			(0.369)	(0.351)	(0.192)
Cables × capital controls × break dummy			0.050	0.026	0.055
			(0.102)	(0.089)	(0.084)
Constant	0.463***	0.274**	0.485***	0.513***	0.468***
	(0.142)	(0.135)	(0.141)	(0.143)	(0.141)
Currency effects	YES	YES	YES	YES	YES
Time effects	YES	NO	YES	YES	YES
Additional controls	YES	YES	YES	YES	YES
Observations	238	238	238	238	238

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country. The basic panel tobit estimates with random effects are reported in column (1); estimates where the cable variables are interacted with a time trend are reported in column (2) and Chow tests for structural breaks in 2001, 2004 and 2007 are reported in columns (3), (4) and (5), respectively. Standard errors reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1, + p<0.2.

Table A7: Estimates Controlling for Time averages of the Exogenous Variables

	(1) Basic estimates	(2) incl. time averages	(3) Basic estimates	(4) incl. time averages	(5) Pooled tobit with FE	(6) Pooled tobit with FE
Time zone distance	-0.463***	-0.392+	-0.430***	-0.256	-0.497***	-0.452***
	(0.127)	(0.258)	(0.126)	(0.359)	(0.130)	(0.139)
Domestic market liquidity	-1.757**	-2.215***	-1.784**	-1.841**	-2.241***	-2.170***
	(0.818)	(0.836)	(0.831)	(0.833)	(0.758)	(0.764)
Capital controls	-0.289+	-0.267+	-0.288+	-0.255+	-0.243+	-0.235+
	(0.186)	(0.193)	(0.190)	(0.197)	(0.173)	(0.176)
Cables	-0.305***	-0.323***	-0.332***	-0.348***	-0.334***	-0.329***
	(0.114)	(0.115)	(0.115)	(0.119)	(0.108)	(0.109)
Cables x time zone distance	0.362***	0.372***	0.361***	0.372***	0.393***	0.385***
	(0.112)	(0.115)	(0.113)	(0.116)	(0.114)	(0.115)
Cables x domestic market liquidity	1.398*	1.812**	1.415*	1.420*	1.852**	1.789**
	(0.814)	(0.831)	(0.827)	(0.828)	(0.754)	(0.759)
Cables x capital controls	0.241+	0.254+	0.243	0.261+	0.236+	0.230
	(0.189)	(0.194)	(0.192)	(0.200)	(0.177)	(0.181)
Constant	0.453***	0.091	0.463***	0.330		
	(0.133)	(0.206)	(0.142)	(0.396)		
Currency effects	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES
Additional controls	NO	NO	YES	YES	NO	YES
Time averages of exogenous variables	NO	YES	NO	YES	NO	NO
Observations	252	252	238	238	252	238

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country. The basic panel tobit estimates with random effects are reported in columns (1) and (3); estimates controlling for the time averages of the exogenous variables are reported in columns (2) and (4); pooled tobit estimates with fixed effects are reported in columns (5) and (6). Standard errors reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p<0.2.

Table A8: Estimates Dropping Observations of Each Year of the BIS Triennial Survey Sequentially

	(1) Full sample	(2) Excl. 1995	(3) Excl. 1998	(4) Excl. 2001	(5) Excl. 2004	(6) Excl. 2007	(7) Excl. 2010	(8) Excl. 2013
Time zone distance	-0.430***	-0.420***	-0.477***	-0.368***	-0.413***	-0.420***	-0.438***	-0.453***
	(0.126)	(0.141)	(0.135)	(0.109)	(0.128)	(0.133)	(0.138)	(0.134)
Domestic market liquidity	-1.784**	-1.722**	-1.034+	-1.961**	-1.899**	-1.817*	-1.701+	-1.690*
	(0.831)	(0.849)	(0.793)	(0.785)	(0.894)	(1.023)	(1.082)	(0.912)
Capital controls	-0.288+	-0.487**	0.055	-0.300+	-0.307+	-0.314+	-0.307+	-0.298+
	(0.190)	(0.208)	(0.214)	(0.208)	(0.204)	(0.217)	(0.216)	(0.217)
Cables	-0.332***	-0.515***	-0.137	-0.326***	-0.344***	-0.349***	-0.348***	-0.319***
	(0.115)	(0.148)	(0.130)	(0.105)	(0.121)	(0.128)	(0.130)	(0.123)
Cables × time zone distance	0.361***	0.336***	0.420***	0.328***	0.363***	0.360***	0.374***	0.368***
	(0.113)	(0.130)	(0.124)	(0.093)	(0.117)	(0.122)	(0.126)	(0.120)
Cables × domestic market liquidity	1.415*	1.372+	0.758	1.560**	1.528*	1.449+	1.353	1.243+
	(0.827)	(0.846)	(0.790)	(0.778)	(0.887)	(1.017)	(1.077)	(0.906)
Cables × capital controls	0.243+	0.477**	-0.119	0.347+	0.200	0.269	0.239	0.201
	(0.192)	(0.213)	(0.213)	(0.216)	(0.204)	(0.219)	(0.218)	(0.218)
Currency effects	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES
Additional controls	YES	YES	YES	YES	YES	YES	YES	YES
Observations	238	213	200	206	203	201	201	204

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country. The basic panel tobit estimates with random effects are reported in column (1) and the subsequent columns show the estimates when observations of each year of the BIS triennial survey is dropped sequentially. Standard errors reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p<0.2.

Table A9: Sensitivity Test to Sample Changes

	(1) Full sample	(2) ARG	(3) BHR	(4) BEL	(5) CHN	(6) DNK	(7) FRA	(8) HKG	(9) ITA	(10) NZL	(11) NOR	(12) POL	(13) RUS	(14) SGP	(15) SVN	(16) SWE	(17) THA	(18) USA
Time zone distance	-0.430***	-0.435***	-0.420***	-0.424***	-0.419***	-0.422***	-0.421***	-0.426***	-0.426***	-0.455***	-0.387***	-0.424***	-0.427***	-0.423***	-0.421***	-0.379***	-0.431***	-0.434***
	(0.126)	(0.125)	(0.126)	(0.123)	(0.120)	(0.124)	(0.122)	(0.126)	(0.124)	(0.134)	(0.106)	(0.125)	(0.127)	(0.125)	(0.121)	(0.107)	(0.126)	(0.128)
Domestic market liquidity	-1.784**	-1.789**	-1.775**	-1.780**	-1.851**	-1.805**	-1.777**	-1.771**	-1.780**	-1.809**	-1.854**	-1.766**	-1.808**	-1.631*	-1.841**	-1.847**	-1.847**	-1.999**
	(0.831)	(0.836)	(0.829)	(0.829)	(0.779)	(0.829)	(0.833)	(0.853)	(0.830)	(0.836)	(0.792)	(0.832)	(0.841)	(0.887)	(0.827)	(0.800)	(0.836)	(0.820)
Capital controls	-0.288+	-0.275+	-0.279+	-0.298+	-0.315*	-0.301+	-0.301+	-0.301+	-0.299+	-0.290+	-0.357*	-0.297+	-0.279+	-0.296+	-0.304+	-0.357*	-0.302+	-0.294+
	(0.190)	(0.190)	(0.189)	(0.190)	(0.177)	(0.189)	(0.192)	(0.193)	(0.190)	(0.192)	(0.183)	(0.189)	(0.192)	(0.192)	(0.189)	(0.183)	(0.191)	(0.191)
Cables	-0.332***	-0.333***	-0.332***	-0.332***	-0.319***	-0.330***	-0.356***	-0.329***	-0.329***	-0.328***	-0.322***	-0.323***	-0.335***	-0.330***	-0.345***	-0.338***	-0.336***	-0.411***
	(0.115)	(0.116)	(0.115)	(0.115)	(0.108)	(0.115)	(0.116)	(0.117)	(0.115)	(0.119)	(0.106)	(0.115)	(0.117)	(0.116)	(0.114)	(0.107)	(0.116)	(0.117)
Cables x time zone distance	0.361***	0.359***	0.362***	0.354***	0.353***	0.353***	0.355***	0.358***	0.357***	0.346***	0.316***	0.357***	0.362***	0.354***	0.349***	0.318***	0.361***	0.370***
	(0.113)	(0.112)	(0.112)	(0.110)	(0.105)	(0.110)	(0.111)	(0.113)	(0.111)	(0.121)	(0.089)	(0.111)	(0.113)	(0.112)	(0.108)	(0.091)	(0.113)	(0.113)
Cables x domestic market liquidity	1.415*	1.419*	1.412*	1.411*	1.476*	1.438*	1.402*	1.406*	1.413*	1.436*	1.493*	1.410*	1.440*	1.258+	1.469*	1.462*	1.469*	1.628**
	(0.827)	(0.832)	(0.825)	(0.824)	(0.774)	(0.824)	(0.828)	(0.848)	(0.825)	(0.831)	(0.788)	(0.828)	(0.836)	(0.883)	(0.823)	(0.795)	(0.832)	(0.815)
Cables x capital controls	0.243+	0.256+	0.247+	0.252+	0.245+	0.260+	0.268+	0.257+	0.247+	0.269+	0.333*	0.261+	0.252+	0.251+	0.255+	0.340*	0.252+	0.268+
	(0.192)	(0.194)	(0.191)	(0.192)	(0.179)	(0.192)	(0.194)	(0.195)	(0.192)	(0.196)	(0.184)	(0.193)	(0.195)	(0.195)	(0.191)	(0.183)	(0.193)	(0.193)
Constant	0.463***	0.479***	0.461***	0.466***	0.461***	0.465***	0.427***	0.453***	0.476***	0.489***	0.451***	0.469***	0.459***	0.463***	0.475***	0.430***	0.467***	0.428***
	(0.142)	(0.142)	(0.142)	(0.141)	(0.138)	(0.142)	(0.139)	(0.145)	(0.141)	(0.145)	(0.135)	(0.143)	(0.143)	(0.143)	(0.139)	(0.133)	(0.144)	(0.145)
Currency effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Additional controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	238	233	232	236	232	232	236	231	236	231	233	232	232	231	236	231	232	231

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country. The basic panel tobit estimates with random effects are reported in column (1) and the subsequent columns reported estimates where observations for a particular country are dropped. Standard errors reported in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$, $^{+}$ $p<0.2$.

Table A10: Estimates controlling for Offshore Financial Centers

	(1) Basic estimates	(2) Offshore center control	(3) Offshore center interactions
Time zone distance	-0.430***	-0.430***	-0.439***
	(0.126)	(0.125)	(0.130)
Domestic market liquidity	-1.784**	-1.769**	-1.883**
	(0.831)	(0.838)	(0.886)
Capital controls	-0.288+	-0.288+	-0.284+
	(0.190)	(0.190)	(0.188)
Cables	-0.332***	-0.331***	-0.332***
	(0.115)	(0.116)	(0.117)
Cables × time zone distance	0.361***	0.360***	0.369***
	(0.113)	(0.113)	(0.117)
Cables × domestic market liquidity	1.415*	1.400*	1.514*
	(0.827)	(0.833)	(0.884)
Cables × capital controls	0.243+	0.245	0.249
	(0.192)	(0.193)	(0.197)
Offshore financial center dummy		-0.025	0.048
		(0.164)	(0.210)
Offshore dummy × cables			-0.079
			(0.335)
Offshore dummy × cables × time zone distance			-0.001
			(0.268)
Offshore dummy × cables × market liquidity			0.090
			(0.610)
Offshore dummy × cables × capital controls			-0.035
			(0.334)
Constant	0.463***	0.464***	0.467***
	(0.142)	(0.142)	(0.143)
Currency effects	YES	YES	YES
Time effects	YES	YES	YES
Additional controls	YES	YES	YES
Observations	238	238	238

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country. The basic panel tobit estimates with random effects are reported in column (1); estimates controlling for offshore financial centers are reported in column (2) and estimates interacting the cable connection variables with the offshore dummy are reported in column (3). Standard errors reported in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$, $^{+}$ $p<0.2$.

Table A11: Estimates with Cable Connections to only London, New York and Tokyo

	(1) Basic estimates	(2) Basic estimates	(3) Only UK cables	(4) Only UK cables	(5) Only JP cables	(6) Only JP cables	(7) Only US cables	(8) Only US cables
Time zone distance	-0.463***	-0.430***	-0.503***	-0.466***	-0.467***	-0.429***	-0.436***	-0.399***
	(0.127)	(0.126)	(0.123)	(0.122)	(0.116)	(0.114)	(0.119)	(0.115)
Domestic market liquidity	-1.757**	-1.784**	-1.758**	-1.803**	-0.968**	-1.191**	-0.921*	-1.157**
	(0.818)	(0.831)	(0.805)	(0.818)	(0.469)	(0.484)	(0.477)	(0.492)
Capital controls	-0.289+	-0.288+	-0.314*	-0.310+	-0.360*	-0.345*	-0.309+	-0.300+
	(0.186)	(0.190)	(0.187)	(0.190)	(0.193)	(0.194)	(0.190)	(0.191)
Cables	-0.305***	-0.332***	-0.392***	-0.413***	-0.395***	-0.410***	-0.285**	-0.308***
	(0.114)	(0.115)	(0.111)	(0.112)	(0.118)	(0.118)	(0.116)	(0.117)
Cables × time zone distance	0.362***	0.361***	0.402***	0.397***	0.376***	0.367***	0.341***	0.336***
	(0.112)	(0.113)	(0.106)	(0.107)	(0.099)	(0.099)	(0.103)	(0.102)
Cables × domestic market liquidity	1.398*	1.415*	1.391*	1.424*	0.615+	0.818*	0.567	0.784*
	(0.814)	(0.827)	(0.800)	(0.813)	(0.440)	(0.452)	(0.448)	(0.461)
Cables × capital controls	0.241	0.243	0.272+	0.271+	0.319+	0.309+	0.257+	0.253+
	(0.189)	(0.192)	(0.190)	(0.193)	(0.196)	(0.197)	(0.193)	(0.194)
Constant	0.453***	0.463***	0.477***	0.479***	0.420***	0.431***	0.413***	0.427***
	(0.133)	(0.142)	(0.126)	(0.135)	(0.123)	(0.131)	(0.128)	(0.137)
Currency effects	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES
Additional controls	NO	YES	NO	YES	NO	YES	NO	YES
Observations	252	238	252	238	252	238	252	238

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country. The basic panel tobit estimates with random effects are reported in columns (1) and (2); estimates with cable connections only to London, New York and Tokyo and reported in columns (3) to (8), respectively. Standard errors reported in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$, $^{+}$ $p<0.2$.

Table A12: Estimates Controlling for Potential Nonlinearities in Capital Controls

	(1) Top-30%	(2) Top-20%	(3) To-10%
Time zone distance	-0.476***	-0.480***	-0.459***
	(0.127)	(0.132)	(0.124)
Domestic market liquidity	-2.233***	-1.767**	-1.716**
	(0.849)	(0.822)	(0.796)
Capital controls	0.220	-0.195	-0.302*
	(0.322)	(0.226)	(0.181)
Cables	-0.299***	-0.291**	-0.293***
	(0.113)	(0.115)	(0.110)
Cables × time zone distance	0.381***	0.377***	0.354***
	(0.111)	(0.117)	(0.108)
Cables × domestic market liquidity	1.882**	1.411*	1.359*
	(0.846)	(0.817)	(0.792)
Cables × capital controls	-0.283	0.132	0.264+
	(0.353)	(0.220)	(0.185)
Threshold dummy	-0.132	-2.880	1.848
	(1.606)	(776.653)	(1,304.992)
Threshold dummy × capital controls	-0.466	2.830	-2.160
	(2.545)	(972.669)	(1,495.253)
Threshold dummy × cables	0.026	2.772	-3.676
	(1.596)	(776.653)	(1,304.992)
Threshold dummy × cables × capital controls	0.581	-2.670	4.151
	(2.532)	(972.669)	(1,495.253)
	(0.076)	(0.077)	(0.074)
Constant	0.452***	0.453***	0.456***
	(0.132)	(0.134)	(0.130)
Currency effects	YES	YES	YES
Time effects	YES	YES	YES
Observations	252	252	252

Notes: The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country as well as binary dummies which equal one if a country is among the top-30%, 20% and 10%, respectively, of the capital control distribution in a given year, and zero otherwise. Standard errors reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p<0.2.

Table A13: Testing for Differences in Major Reserve/G10 currencies

	(1)	(2)	(3)	(4)
	incl. reserve dummy		incl. G10 dummy	
Time zone distance	-0.381***	-0.355***	-0.349**	-0.347**
	(0.131)	(0.126)	(0.145)	(0.143)
Domestic market liquidity	-2.333***	-2.290***	-2.091**	-2.042**
	(0.845)	(0.864)	(0.825)	(0.840)
Capital controls	-0.248+	-0.245+	-0.210	-0.222
	(0.183)	(0.187)	(0.192)	(0.195)
Cables	-0.282**	-0.303**	-0.182	-0.253+
	(0.124)	(0.124)	(0.188)	(0.189)
Cables × time zone distance	0.345***	0.339***	0.267*	0.295*
	(0.120)	(0.116)	(0.159)	(0.158)
Cables × domestic market liquidity	1.427+	1.461+	1.706*	1.756*
	(0.871)	(0.896)	(0.893)	(0.912)
Cables × capital controls	0.223	0.238	0.283+	0.315+
	(0.188)	(0.190)	(0.205)	(0.209)
Reserve/G10 dummy	0.652***	0.573**	0.571***	0.504***
	(0.227)	(0.225)	(0.147)	(0.149)
Reserve/G10 dummy × cables	-0.111	-0.106	-0.101	-0.036
	(0.190)	(0.188)	(0.179)	(0.179)
Reserve/G10 dummy × cables × time zone distanc	-0.047	0.084	0.126	0.096
	(0.365)	(0.343)	(0.125)	(0.122)
Reserve/G10 dummy × cables × market liquidity	0.532	0.434	0.031	-0.081
	(0.496)	(0.550)	(0.515)	(0.578)
Reserve/G10 dummy × cables × capital controls	-0.378	-0.165	-1.109**	-1.056**
	(1.312)	(1.311)	(0.475)	(0.477)
Constant	0.294**	0.267*	0.177	0.187
	(0.140)	(0.154)	(0.165)	(0.174)
Currency effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
Additional controls	NO	YES	NO	YES
Observations	252	238	252	238

Notes: The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effects of submarine fiber-optic cable connections of the currency issuing country as well as interactions with a reserve currency issuer dummy (columns 1 and 2) or a G10 dummy (columns 3 and 4). Standard errors reported in parentheses; *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p<0.2.

Table A14: Robustness – Only Point-to-Point Submarine Cable Connections

	(1) Panel tobit	(2) Panel tobit	(3) Panel GLM	(4) Panel GLM	(5) Random effects	(6) Random effects	(7) Pooled OLS
Time zone distance	-0.324***	-0.302***	-0.802***	-0.842***	-0.228***	-0.208***	-0.205+
	(0.083)	(0.080)	(0.189)	(0.195)	(0.025)	(0.004)	(0.075)
Domestic market liquidity	-1.741**	-1.817**	-4.286**	-4.129***	-1.056***	-0.913***	-1.670**
	(0.824)	(0.838)	(1.699)	(1.516)	(0.109)	(0.136)	(0.182)
Capital controls	-0.084	-0.074	-0.231	-0.385	-0.062**	-0.112**	-0.043
	(0.138)	(0.141)	(0.332)	(0.307)	(0.025)	(0.051)	(0.060)
Cables	-0.259***	-0.297***	-0.681**	-0.783**	-0.149**	-0.159**	-0.207+
	(0.100)	(0.103)	(0.343)	(0.323)	(0.073)	(0.079)	(0.086)
Cables × time zone distance	0.276***	0.289***	0.845***	0.854***	0.189***	0.184***	0.198*
	(0.070)	(0.071)	(0.210)	(0.197)	(0.040)	(0.028)	(0.053)
Cables × domestic market liquidity	1.377*	1.444*	3.444**	3.289**	0.773***	0.627***	1.339**
	(0.818)	(0.833)	(1.711)	(1.533)	(0.090)	(0.139)	(0.186)
Cables × capital controls	-0.027	-0.040	-0.446	-0.232	-0.105+	-0.084	-0.024
	(0.159)	(0.164)	(0.439)	(0.432)	(0.077)	(0.112)	(0.079)
Trade integration		-0.086		-0.132		-0.050	
		(0.071)		(0.175)		(0.043)	
Financial integration		0.088+		0.096		0.023	
		(0.062)		(0.171)		(0.042)	
Flexible exchange rate regime		0.137**		0.412**		0.092**	
		(0.054)		(0.182)		(0.046)	
Carry trades		-0.005**		-0.015		-0.001	
		(0.002)		(0.016)		(0.002)	
Constant	0.354***	0.375***	-0.099	-0.060	0.409***	0.408***	0.210+
	(0.115)	(0.124)	(0.282)	(0.350)	(0.043)	(0.064)	(0.081)
Currency effects	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES
Observations	252	238	252	238	252	238	252
R^2					0.377	0.429	0.858
ρ	0.802	0.762			0.748	0.671	

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effect of point-to-point submarine fiber-optic cable connections to the U.K., U.S. or Japan (i.e. the three countries where the matching servers of EBS/Reuters for electronic trading are located). Panel tobit estimates with random effects are reported in columns (1) and (2); panel GLM estimates are reported in columns (3) and (4); linear panel estimates with random effects are reported in columns (5) and (6); and pooled OLS estimates with currency fixed effects are reported in column (7). The standard errors reported in parentheses in columns (3) to (7) are robust to heteroskedasticity and those in columns (5) to (7) are clustered by time zone (i.e. Asian, European, and US trading hours); *** p<0.01, ** p<0.05, * p<0.1, + p<0.2.

Table A15: Robustness – Number of Submarine Cable Connections

	(1) Panel tobit	(2) Panel tobit	(3) Panel GLM	(4) Random effects	(5) Random effects	(6) Pooled OLS
Time zone distance	-0.239***	-0.284***	-0.505**	-0.161***	-0.193***	-0.064
	(0.076)	(0.077)	(0.257)	(0.032)	(0.050)	(0.050)
Domestic market liquidity	-0.866*	-0.982**	-1.065	-0.342***	-0.201+	-1.210**
	(0.449)	(0.499)	(1.992)	(0.083)	(0.151)	(0.240)
Capital controls	-0.171+	-0.137	-0.576+	-0.122***	-0.192***	-0.094
	(0.120)	(0.121)	(0.358)	(0.022)	(0.010)	(0.075)
Cables	-0.018***	-0.017***	-0.035***	-0.009***	-0.010***	-0.014**
	(0.004)	(0.004)	(0.009)	(0.003)	(0.003)	(0.002)
Cables × time zone distance	0.014***	0.024***	0.043***	0.010***	0.016***	0.011+
	(0.004)	(0.005)	(0.012)	(0.003)	(0.002)	(0.005)
Cables × domestic market liquidity	0.014*	0.016*	0.015	0.004+	0.001	0.020**
	(0.009)	(0.009)	(0.036)	(0.002)	(0.004)	(0.004)
Cables × capital controls	0.011	0.007	0.016	-0.002	0.004	-0.003
	(0.015)	(0.015)	(0.039)	(0.012)	(0.008)	(0.008)
Trade integration		-0.021			-0.044	
		(0.076)			(0.036)	
Financial integration		0.014			-0.002	
		(0.063)			(0.034)	
Flexible exchange rate regime		0.146***			0.109**	
		(0.056)			(0.047)	
Carry trades		-0.004*			-0.001	
		(0.002)			(0.002)	
Constant	0.227**	0.227*	-0.456	0.317***	0.341***	0.005
	(0.112)	(0.121)	(0.356)	(0.030)	(0.042)	(0.003)
Currency effects	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES
Observations	252	238	252	252	238	252
R^2				0.309	0.371	0.862
ρ	0.860	0.842		0.742	0.681	

Notes. The table reports estimates of model equation (1) where the share of foreign exchange trading occurring offshore is regressed on the standard determinants of the geography of foreign exchange trading as well as the direct and interacted effect of the number of submarine fiber-optic cable connections of the currency issuing country. Panel tobit estimates with random effects are reported in columns (1) and (2); panel GLM estimates are reported in columns (3); linear panel estimates with random effects are reported in columns (4) and (5); and pooled OLS estimates with currency fixed effects are reported in column (6). The standard errors reported in parentheses in columns (3) to (6) are robust to heteroskedasticity and those in columns (4) to (6) are clustered by time zone (i.e. Asian, European, and US trading hours); *** $p<0.01$, ** $p<0.05$, * $p<0.1$, $^{+}p<0.2$.

Table A16: Descriptive Statistics

	Unit	Obs	Mean	Std. Dev.	Min	Max
Share of FX trading occuring offshore	%	270	0.391	0.324	0	1
Time zone distance	Hours	270	1.207	0.796	0	4
Domestic market liquidity	$ trillion	270	0.054	0.198	0	2.353
Capital controls	Index	252	0.315	0.320	0	1
Cables	Binary dummy	385	0.543	0.499	0	1
Trade integration	Exports plus imports scaled by GDP, %	270	0.764	0.622	0.132	3.603
Financial integration	Net external financial assets scaled by GDP, %	268	-0.001	0.715	-1.549	2.960
Flexible exchange rate regime	Binary dummy	385	0.229	0.420	0	1
Carry trades	Percentage points	250	2.914	8.159	-4.979	88.060

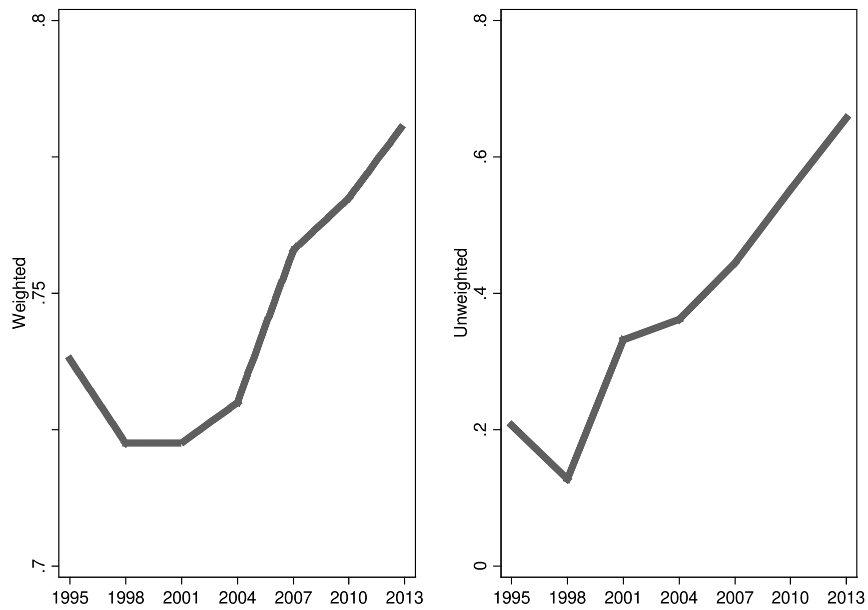
Notes. The table reports descriptive statistics on the variables used to estimate model equation (1).

Table A17: List of the Currencies included in the Sample

ARS	Argentinean peso	ITL	Italian lira
ATS	Austrian schilling	JPY	Japanese yen
AUD	Australian dollar	KRW	Korean won
BEF	Belgian franc	LTL	Lithuanian litas
BGN	Bulgarian lev	LUF	Luxembourg franc
BHD	Bahraini dinar	LVL	Latvian lats
BRL	Brazilian real	MXN	Mexican peso
CAD	Canadian dollar	MYR	Malaysian ringgit
CHF	Swiss franc	NLG	Dutch guilder
CLP	Chilean peso	NOK	Norwegian krone
CNY	Chinese renminbi	NZD	New Zealand dollar
COP	Colombian peso	PEN	Peruvian sol
CZK	Czech koruna	PHP	Philippines peso
DEM	German mark	PLN	Polish zloty
DKK	Danisk krone	PTE	Portuguese escudo
EEK	Estonian kroon	RON	Romanian leu
ESP	Spanish peseta	RUB	Russian ruble
EUR	European euro	SAR	Saudi riyal
FIM	Finnish markka	SEK	Swedish krona
FRF	French franc	SGD	Singapore dollar
GBP	Pound sterling	SIT	Slovenian tolar
GRD	Greek drachma	SKK	Slovak koruna
HKD	Hong Kong dollar	THB	Thai bath
HUF	Hungarian forint	TRY	Turkish lira
IDR	Indonesian rupiah	TWD	Taiwanese dollar
IEP	Irish pound	USD	US dollar
ILS	Israeli Shekel	ZAR	South African rand
INR	Indian rupee		

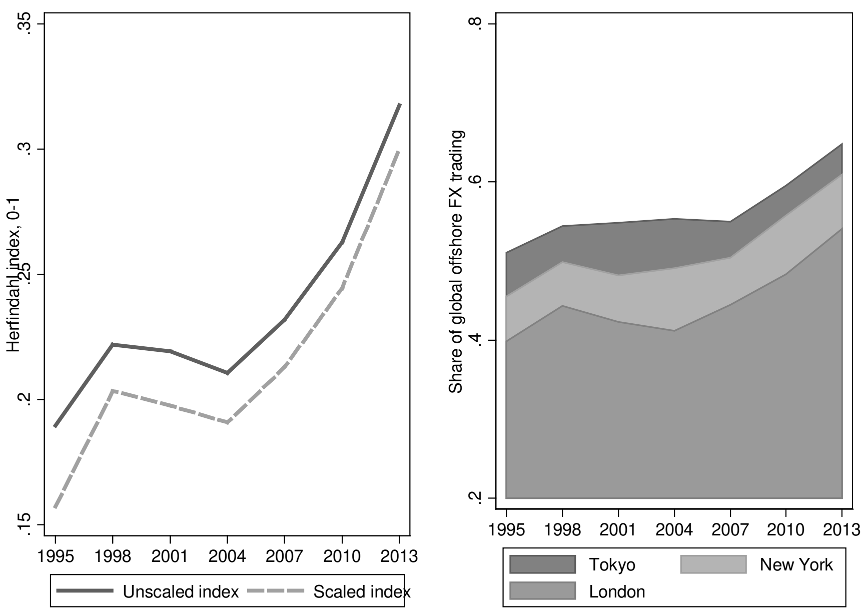
Notes. The table reports the 55 currencies included in the sample together with their ISO codes.

Figure A1: Offshore Foreign Exchange Trading
– Weighted vs. Un-weighted Global Averages



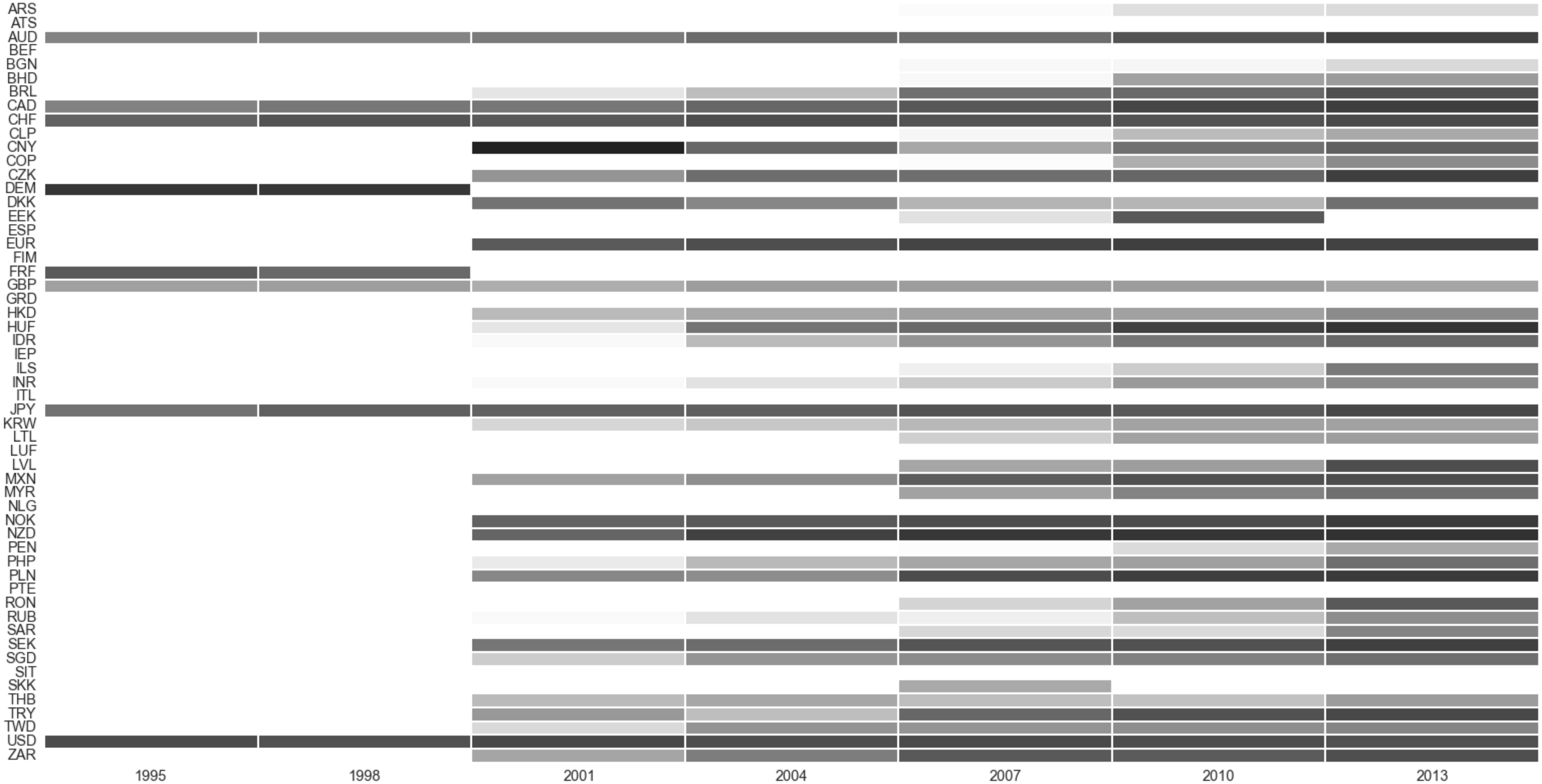
Notes. This figure shows the evolution between 1995 and 2013 of the weighted (left-hand side panel) and un-weighted (right-hand side panel) global averages of foreign exchange trading occurring offshore. The weighted average, which is subject to a theoretical 50%-lower bound, is the sum of foreign exchange trading occurring offshore in all currencies scaled by the sum of total (onshore and offshore) foreign exchange trading in all currencies. The unweighted average is the arithmetic average of the individual currency shares.

Figure A2: Importance of London, New York and Tokyo for Offshore FX trading



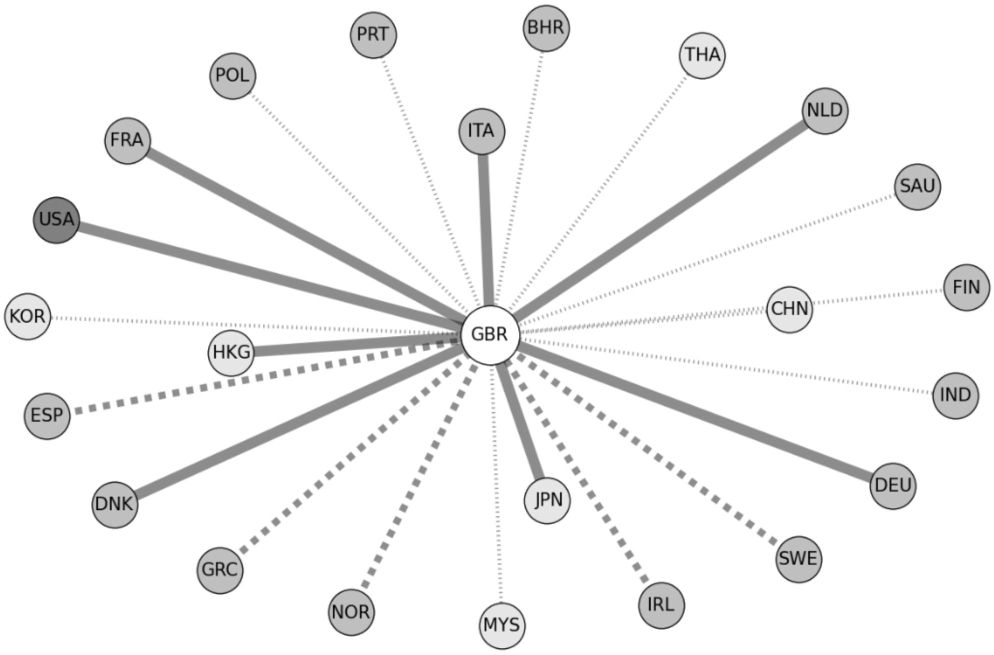
Notes. This figure shows the evolution between 1995 and 2013 of the scaled and unscaled Herfindahl indices of concentration of global foreign exchange trading occurring offshore for London (U.K.), New York (U.S) and Tokyo (Japan) in the left-hand-side panel, as well as the cumulated share of global foreign exchange trading accounted for by these three financial centers in the right-hand side panel.

Figure A3: Offshore Foreign Exchange Trading between 1995 and 2013 – Breakdown by Currency



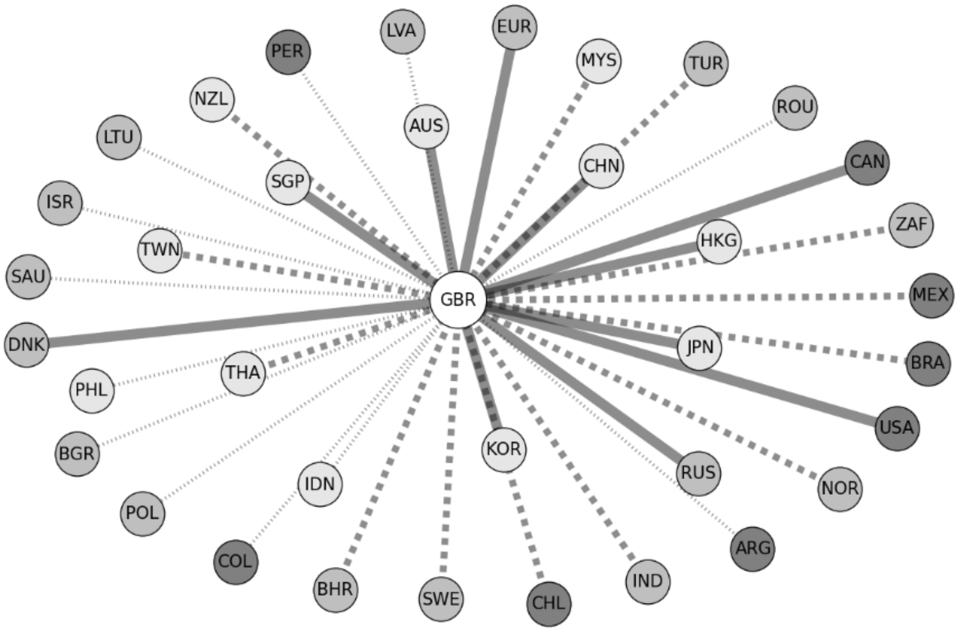
Notes. This figure shows the evolution between 1995 and 2013 of the share of foreign exchange trading occurring offshore for our sample's 55 units between 1995 and 2013. Darker shades of grey indicate higher shares of trading occurring offshore (actual shares are not reported for confidentiality reasons). White cells indicate that the data are unavailable or not reported.

Figure A4: Submarine Fiber-Optic Cable Connections to the UK – *1998*



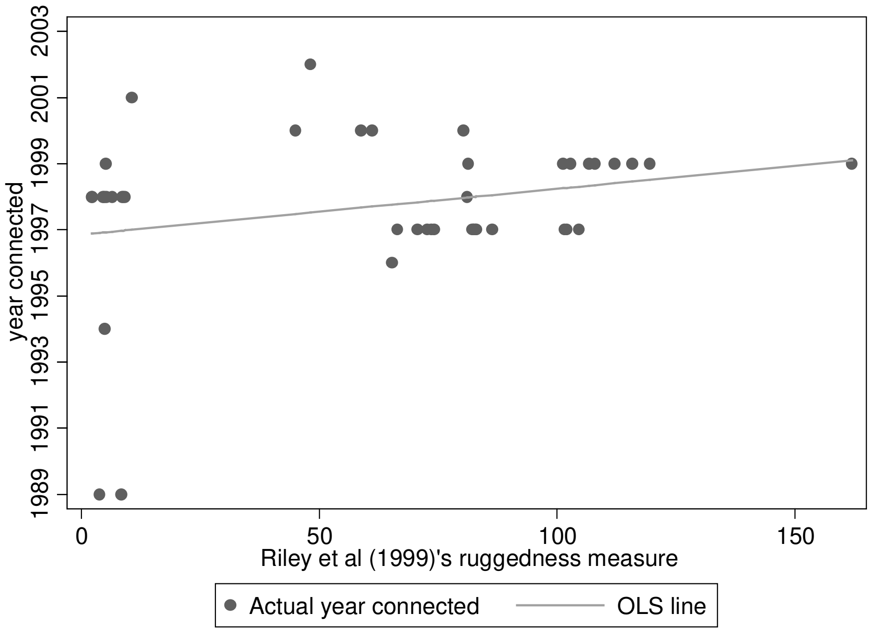
Notes. This figure shows the network of countries connected (point-to-point or via third countries) to the UK (one of the three countries where the matching servers of EBS/Reuters for electronic foreign exchange trading are located) via a submarine fiber-optic cable in 1998. Countries located in the time zone corresponding to Asian trading hours are shown as light grey nodes, against grey nodes for those located in the time zone corresponding to European trading hours and dark grey nodes for US trading hours. Solid lines indicate countries whose currencies ranked in the top third by FX turnover; dashed line those in the middle third, and dotted lines those in the bottom third.

Figure A5: Submarine Fiber-Optic Cable Connections to the UK – *2013*



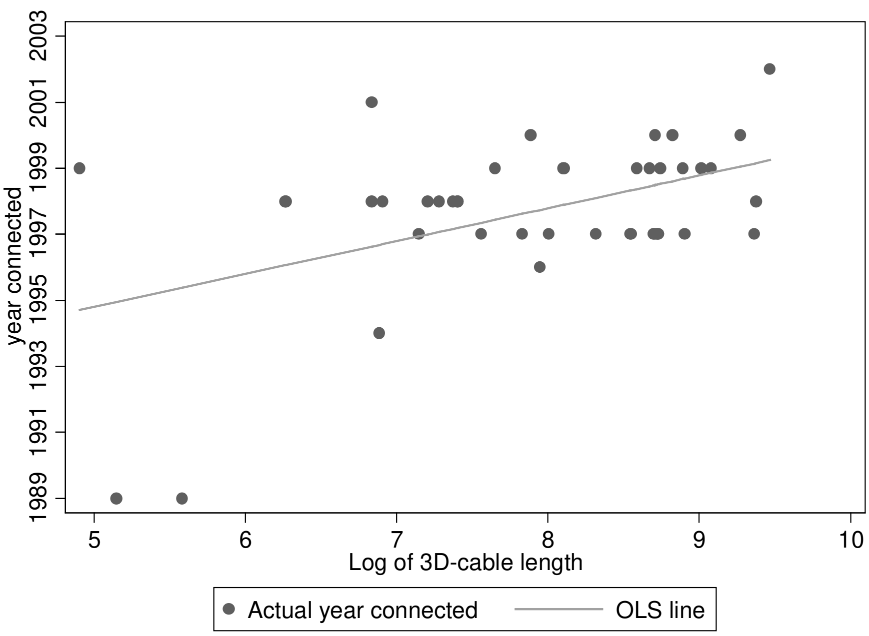
Notes. This figure shows the network of countries connected (point-to-point or via third countries) to the UK (one of the three countries where the matching servers of EBS/Reuters for electronic foreign exchange trading are located) via a submarine fiber-optic cable in 2013.

Figure A6: Connection Year vs. Ruggedness



Notes. This figure plots our Riley et al. (1999)'s measure of ruggedness of the seabed, i.e. of topological irregularities such as domes, canyons or faults, against the actual year when countries were connected to the internet backbone.

Figure A7: Connection Year vs. Cable 3-D Length



Notes. This figure plots our estimates of the 3-dimensional length of the cables, which takes into account of topological irregularities of the seabed, against the actual year when countries were connected to the internet backbone.