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Thick vs. Thin-Skinned: Technology, News, and Financial Market Reaction

By Barry Eichengreen[#], Romain Lafarguette[†] and Arnaud Mehl[*]

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Monetary and Capital Markets Department

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Abstract

We study the impact of technology on the reaction of financial markets to information, focusing on the foreign exchange market. We contrast the "thin-skinned" view that technological improvements cause markets to react more to new information with the "thick-skinned" view that they react less. We pinpoint exogenous technological changes using the timing of the connection of countries via the submarine fiber-optic cables used for electronic trading. Cable connections dampen the response of exchange rates to macroeconomic news, consistent with the "thick-skinned" hypothesis. This is in line with the view that technology eases access to information and reduces trend-following behavior. According to our estimates, cable connections reduce the reaction of exchange rates to U.S. monetary policy news by 50 to 80 percent.

Key words: Technology, Submarine Fiber-Optic Cables, Foreign Exchange Market, Macro Announcements

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Contents Page

Tables

Figures

I. INTRODUCTION

Understanding how market participants process and respond to new information is a classic issue in financial economics.[1] It is also timely: in the last six years, financial markets have repeatedly experienced the large, sudden, disruptive price movements known as "flash crashes." On May 6, 2010, for example, the S&P 500, Dow Jones Industrial Average and Nasdaq Composite collapsed for a few minutes but then rebounded in the absence of a clear trigger – that is, in response to at most minor bits of news (see e.g., Kirilenko et al. 2015). It has been argued, on the basis of casual observation of such episodes, that progress in information and communication technology (ICT) has caused financial markets to react more violently to small bits of information.

Evidence on the extent of the phenomenon remains scant, however, and even the direction of the effect can be questioned. That is to say, there are two opposed hypotheses about how ICT affects the reaction of financial markets to new information.

One hypothesis, which we call the "thin-skinned" hypothesis, is that ICT causes asset prices to react *more*. For example, it facilitates trading strategies associated with volatility. Algorithmic trading, algorithmic trading errors, stop-losses and the execution of automated fire-sale programs have all been said to amplify price movements (see e.g., CGFS 2001, Kirilenko and Lo 2013, and Lo 2016).[2] Strategies used by high frequency traders to profit from slower traders (strategies known as "stuffing" ,"smoking" and "spoofing") are thought to heighten volatility as well (see inter alia Lee et al. 2013, Brogaard et al. 2014, Hasbrouck 2015, and Dobrev and Schaumburg 2016).[3] ICT may also help traders gather information about the sentiment and actions of other traders by, for example, enabling them to use social media. Traders can use information from

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[1] The literature is too extensive to be summarized here. But considering just the reaction of exchange rates to news, which is our focus here, key contributions include e.g., Cornell (1983), Engel and Frankel (1984), Hardouvelis (1984), Ito and Roley (1987), Faust et al. (2007), Ederington and Lee (1993), Andersen et al. (2003), Evans and Lyons (2008) and Love and Payne (2008).

[2] As Lo puts it (drawing on Murphy's Law, which originated in the context of the postwar aviation and rocket industry): "whatever can go wrong, will go wrong faster and bigger when computers are involved" (Lo 2016, pp. 2-3).

[3] "Stuffing" is submitting a large number of orders; "smoking" is posting alluring limit orders to attract slow traders while executing trades on less generous terms; while "spoofing" involves placing a large number of orders in the opposite direction to the fast trader's true intentions in order to lure slower traders and move prices to the benefit of the fast trader.

Twitter messages, for example, to infer market sentiment in real time, a practice that some observers argue gives rise to spurious rumors and volatility.[4]

In models with strategic complementarities between traders, dissemination of public information enabled by ICT may similarly increase volatility and be detrimental to welfare. In the model of Morris and Shin (2002), for instance, agents have access to public and private information on underlying fundamentals and aim to take actions appropriate to the underlying state. If the agents in question are subject to strategic complementarities and seek to second-guess one another's actions, it is rational for them to underreact to private information and overreact to public information. Hence unwarranted public news or mistaken disclosures may create greater volatility and reduce welfare.[5]

The "thick-skinned" hypothesis posits that ICT causes asset prices to react *less* because it reduces the informational disadvantage of poorly informed investors. Brennan and Cao (1997) and Brennan et al. (2005) analyze a noisy rational expectations model in which uninformed investors follow and amplify market trends by relying excessively on actual or past returns to anticipate future returns. Uninformed investors buy when asset prices rise and sell when they fall, amplifying market reactions. ICT, by helping to level the informational playing field, reduces this trend-following behavior. It eases access to information of poorly informed investors, who otherwise have to rely mostly on public signals extracted from observed prices, unlike well-informed investors, who can rely more on private signals, and hence who tend to act as contrarians.

Testing these hypotheses is not easy. Doing so requires a measure of technology that is exogenous to financial variables. Ideally this measure would be time varying, spatially localized, and heterogeneous across time and space.

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[4] One example is the fake tweet from the Associated Press' hacked Twitter account, reporting explosions at the White House that injured President Obama (for details see e.g., the article by Matthew Phillips entitled "How Many HFT Firms Actually Use Twitter to Trade" released on 24 April 2013 in Bloomberg).

[5] As Morris and Shin discuss, there is a trade-off between timely but noisy releases of statistical data and slow but more accurate releases. Publication of preliminary or incomplete data might be unwarranted since the benefit of early release may be more than outweighed by the disproportionate impact of any error. This explains why some countries have reduced the frequency of releases of certain macroeconomic indicators and others discussed discontinuing publication of preliminary estimates (see Morris and Shin 2002, p. 1523).

In this paper we propose such a measure, namely the point-to-point connections to fiber-optic submarine cables that form the backbone of the internet. We focus on reactions to news in the global foreign exchange market and how it is conditioned by those connections. This is an attractive case study because the foreign exchange market is the single largest financial market in the world, when measured by turnover. It is disbursed geographically, and transactions in the market are standardized. It is attractive because the submarine fiber optic cables in question connected different countries at different points in time and were not laid for purposes related to trading foreign exchange.[6]

We estimate the impact of cable connections on the response of bilateral exchange rates against the U.S. dollar to global macroeconomic news (news about policy interest rates, GDP, industrial production, CPI inflation, unemployment, and trade balances) using daily observations for 56 currencies between 1997 and 2015.

We find that cable connections, on balance, dampen the response of exchange rates to news, consistent with the “thick-skinned” hypothesis. This result is consistent with the view that technology levels the informational playing field by easing access to information and that it thereby reduces trend-following behavior. The effect can be large: our estimates suggest that cable connections reduce the reaction of exchange rates to U.S. monetary policy news by 50 to 80 percent.

Section II provides a brief primer on submarine fiber-optic cables. Section III reviews our empirical framework and hypotheses. Section IV presents the basic results. Section V turns to extended results and robustness checks, after which Section VI concludes and draws implications for policy.

[6] This is in the spirit of studies that use geographical attributes and related infrastructure as sources of exogenous variation. Acemoglu, Johnson and Robinson (2005) used direct access to the Atlantic Ocean, while Acemoglu, García-Jimeno and Robinson (2015) considered colonial roads built in Colombia in the eighteenth century. It is also in the spirit of studies utilizing exogenous changes in geographic proximity, such Giroud (2013) who uses the introduction of new airline routes between headquarters and plants to gauge the impact on plant-level investment and productivity.

II. A BRIEF PRIMER ON SUBMARINE FIBER-OPTIC CABLES

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.[7] Cables covered with 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. 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 had reliability and capacity problems. In the absence of repeater amplifiers, high voltages were required to transmit signals over long distances, creating distortion, limiting carrying capacity and leading to 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 was development of a practical vacuum-tube-based repeater amplifier in the opening years of the twentieth century. Commercialization was then delayed by the two world wars and the Great Depression.

The first modern submarine cable, Transatlantic No. 1 (TAT-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 U.K. 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 thirty-sixth channel. The 1960s saw the development of coaxial cables of somewhat greater

[7] A detailed account of the early history of submarine cables is Wenzlhuemer (2013). The account here is drawn from Eichengreen, Lafarguette, and Mehl (2016).

reliability and carrying capacity that operated with narrower bandwidths and utilized transistors rather than vacuum tubes as repeaters.[8]

Coaxial cables were superseded in the 1980s by fiber-optic cables. Fiber-optic cables are made by stretching glass (or silica) to roughly the diameter of a human hair. 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); latency time will be important to our subsequent story. Fiber optic cable connections also increase bandwidth (i.e., the amount of data that can be put through per unit of time) significantly relative to coaxial cables. They reduce losses in signal transmission over long distances. 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 the 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 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, who built it mainly to carry telephonic traffic in competition with AT&T and British Telecom.

Overall, the existence of a cable link between two countries can be regarded as exogenous to foreign exchange trading. First, the layout of the submarine cable network is heavily influenced by geographical constraints related to seabed topography. Submarine cables can only connect

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[8] 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.

terrestrial points with direct access to the ocean. Landing points are carefully chosen to be in areas with gently sloping, sandy or silty sea-floors and without strong currents, so as to minimize costs and risk of damage.[9]

Second, the fiber-optic cable network is heavily shaped by the earlier telegraph and coaxial networks of the nineteenth century and immediate post-World War II period. Information about seabed conditions, landing sites and other natural and manmade hazards is incomplete and, in practice, inferred from earlier experience. As a result, the contours of today's fiber-optic cable network mirror those of the earlier telegraph network laid in the 1950s and of the coaxial network laid in the 1950s, 1960s and 1970s. These earlier networks provided information about and served to establish which routes are disruptive-current free and which landing points are convenient. Those contours of earlier networks are of course similarly exogenous to current foreign-exchange-market considerations.

Relatedly, the geography of the submarine fiber-optic cable network is further shaped by safety and strategic considerations. Once a route is seen by the cable industry as secure, because it has been shown by past experience to be sheltered from man-made interference such as wars, sabotage, and terrorist attacks, incentives to stick to it are strong.[10]

In addition, high installation and maintenance costs mean that submarine fiber-optic cables are typically owned by large telecommunication consortia, not by financial institutions active in the foreign exchange market.

Finally, and arguably most importantly, fiber-optic cables laid between 1989 and the early 2000s, the key period considered here, were laid for general telecommunication purposes, in other words for carrying long-distance telegraphic communication, telephone calls, fax and internet transmission. They were not laid to facilitate electronic trading. Press coverage from the late 1980s and early 1990s emphasize that increases in efficiency and capacity for telephone calls, fax and television transmission were the main reasons for developing and investing in submarine fiber-optic cables.[11]

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[9] This explains why Singapore, which is a peninsula, has more cable connections (21) than mainland China (12), which is a much larger economy.

[10] The early telegraph network of the nineteen century was mapped over colonial geographies for similar military reasons.

[11] See Eichengreen, Lafarguette and Mehl (2016) for examples of the press reports in question.

Things were different after 2010, the year when Spread Networks unveiled an 827-mile 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). This cable reduced latency time from 17 to 13 milliseconds (see Lewis 2014); it is the first example of which we are aware of a terrestrial cable laid for the purpose of electronic trading. Hibernia Express, which was tested in September 2015, is the first submarine cable laid for the express purpose of electronic trading. The existence of these recent cables does not affect our empirical strategy, however. We only use submarine cables laid between 1989 and 2002, i.e., almost a decade before investors sought to lay them with electronic trading in mind.[12]

By 2006, 99 percent of international communications traffic was carried by submarine cables and the remainder 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 much lower latency, larger bandwidth and reliability performance than satellite transmission.[13]

Since cables were laid and came into use at different points in time, the network of active submarine cables provides us with a source of exogenous changes that vary over both space and time. This is illustrated in Figure 1 which shows the evolution of the connectivity of the 56 countries of our sample to the network of submarine fiber-optic cables using a dummy variable which takes a value of one if a country is point-to-point connected via a submarine fiber-optic cable to the world's three largest foreign exchange markets (the U.S., the U.K. and Japan – whose importance for identification is discussed below) and zero otherwise.[14] This time and spatial heterogeneity enables us to identify the causal effects of technology on the reaction of exchange rates to news.

[12] This means that the existence of a cable link can be regarded as econometrically exogenous with respect to the outcomes in the foreign exchange market. Still more recent cables, backed by Google, connecting Florida with Brazil, Southeast Asia with Japan, and Japan with California, are similarly being built with the Internet in mind and not high speed trading.

[13] Might earlier telephonic cables, before the advent of fiber optics, have had a comparable similar effect on the volatility of the foreign exchange market? We doubt this. Earlier cables transmitted data and orders less quickly and reliably. High-frequency trading, for example, was not possible with earlier telephonic cables. Electronic trading also developed because market infrastructure (including the matching servers of EBS and Thomson Reuters) was now able to handle large numbers of simultaneous orders at high frequency. Such infrastructure was not feasible (it was non-existent) before the 1990s because it requires large data storage capacity and fast computing, which were beyond technical capabilities in the earlier period.

[14] Singapore overtook Japan as the world's third largest foreign exchange market in 2016.

III. EMPIRICAL FRAMEWORK AND HYPOTHESES

Our theoretical framework derives from the literature on the microstructure of the foreign exchange market and specifically on the effects of macroeconomic news (Andersen et al. 2003). This literature treats the exchange rate as a forward-looking asset price, as in Engel and West (2005).

Specifically, the log exchange rate s_t is taken as a function of the discounted value of market expectations about future fundamentals f_{t+i}:

$$s_t = (1-\theta)\sum_{i=0}^{\infty}\theta^i E_t[f_{t+i}|\Omega_t],$$

where Ω_t is public information available at time *t*, and θ is the discount factor. To understand the effect of macroeconomic announcements on exchange rate returns $r_t = s_t - s_{t-1}$, consider a dynamic specification of the form:

$$r_t = s_t - s_{t-1} = (1-\theta)\sum_{i=0}^{\infty}\theta^i \{E_t[f_{t+i}|\Omega_t] - E_{t-1}[f_{t+i-1}|\Omega_{t-1}]\}.$$

This implies that returns are driven by changes in market expectations about future fundamentals. The news component of macroeconomic announcements is an example of such fundamentals (see below for a more precise definition of the news component of the latter).

This framework provides a foundation for our baseline empirical specification insofar as it suggests that information is a relevant explanatory variable for exchange rate returns. Our basic model seeks to estimate how the reaction of exchange rates to new information changes with activation of point-to-point connections to fiber-optic submarine cables.

We use different exchange rate returns to quantify those changes. Following Andersen et al. (2003), we operationalize macroeconomic news as the normalized difference between the realized value of a given macroeconomic indicator and the value expected by market participants:

$$S_t^k = \frac{A_t^k - F_t^k}{\hat{\sigma}_k}, \forall k \in I,$$

where A_t^k is the announced value of macroeconomic indicator *k*, F_t^k is the market expected value of indicator *k* at time *t*, and $\hat{\sigma}_k$ is the estimated sample standard deviation of $(A_t^k - F_t^k)$.

In practice I is a set of information indicators that includes announcements about U.S. real GDP, CPI inflation, industrial production, the unemployment rate, the trade balance, and the monetary policy interest rate. Our data on macroeconomic announcements are from Bloomberg. Their expected values are the medians of forecasts made by professional forecasters, collected by Bloomberg shortly before announcement of the macroeconomic indicators in question. If announcement days are known in advance and surveys of market expectations are realized before macroeconomic data are released, then news can be taken as exogenous with respect to these other economic developments. Using standardized news (in other words scaling the difference between the announced and expected values of the indicator in question by its respective standard deviation $\hat{\sigma}_k$) facilitates comparisons of responses of exchange rates to different pieces of news.

We focus on U.S. news because the exchange rates we analyze are bilateral rates vis-à-vis the dollar (this is also the practice of Andersen et al. 2003). In addition, other recent studies (e.g., Rey 2013, 2016; Miranda-Agrippino and Rey 2015; Obstfeld 2015; Passari and Rey 2015) stress the powerful role of U.S. monetary policy in driving "global financial cycles" and movements in a wide variety of asset prices, not just in the U.S. but globally.

We model the effect of ICT through point-to-point cable connections between the locations of the matching servers of Electronic Brokerage Services (EBS) and Thomson Reuters (the two main electronic platforms where dollars are heavily traded against other currencies), i.e., in New York, London, and Tokyo, and financial centers in other countries. We posit that a country's connection to the U.K., the U.S. or Japan via a submarine fiber-optic cable reduces latency time and increases bandwidth. We think of the relevant market information as not just the data releases but also analysis and interpretation of the announcement by dealers, banks, consultancies and research organizations in the same location, insofar as that is where the context needed to process the new information is best understood.

We start by replicating the estimates of Andersen et al. (2003) but for 56 currencies as opposed to their 5, and for 17 years as opposed to their 6. We estimate:

$$r_{j,t} = \alpha_j + \sum_{k \in I} \beta^k S_t^k + \varepsilon_{j,t}, \qquad (1)$$

where $r_{j,t}$ is the daily log exchange rate return against the U.S. dollar for the currency of country *j* at time *t*, S_t^k the standardized news associated with the announced value of U.S. macroeconomic indicator *k* at time *t*, α_j is a currency fixed-effect, and $\varepsilon_{j,t}$ the residuals.

We then consider the impact of fiber-optic cable connections by modifying Equation (1) to take the form:

$$r_{j,t} = \alpha_j + \sum_{k\in I} \beta^k S_t^k + \gamma\, Cables_{j,t} + \sum_{k\in I}\left[\delta^k S_t^k \times Cables_{j,t}\right] + \varepsilon_{j,t}, \qquad (2)$$

where $Cables_{j,t}$ is a dummy variable equaling one if country *j* has a point-to-point connection to EBS and Reuters matching servers at time *t* and 0 otherwise. Point-to-point means that the cable connection directly links the two countries as opposed to being routed through a third country. We consider both direct effects of cable connections and interaction terms (we interact the presence of a cable connection with the standardized news).

Our test of the "thin-skinned" hypothesis is that:

$$H_0: \left|E\left[r_{j,t}\middle|S_t^k, Cables_{j,t} = 1\right]\right| > \left|E\left[r_{j,t}\middle|S_t^k, Cables_{j,t} = 0\right]\right|,$$

where rejecting H_0 is evidence against the hypothesis. Conversely, our test of the "thick-skinned" hypothesis is that:

$$H_0: \left|E\left[r_{j,t}\middle|S_t^k, Cables_{j,t} = 1\right]\right| \leq \left|E\left[r_{j,t}\middle|S_t^k, Cables_{j,t} = 0\right]\right|,$$

where rejecting H_0 is evidence against the hypothesis.

We use observations for 56 bilateral exchange rates against the U.S. dollar between January 1, 1997 and November 30, 2015, for a total of 240,430 observations. Data were taken from Bloomberg using daily fixings at New York closing time (17:00 p.m. E.S.T.).

Figure 2 shows the distribution of exchange returns (in percent) as well as of the standardized U.S. macroeconomic news (in standard deviations). Casual observation suggests, for instance, that US policy rate announcements are frequently anticipated by market, although there are also exceptions that sometimes give rise to sizeable news shocks.[15]

[15] They were not anticipated by market participants in six instances, specifically.

We take our data on the network of submarine fiber-optic cables from TeleGeography's interactive Submarine Cable Map.[16]These data were collected by Global Bandwidth Research, a consultancy specializing in analysis of long-distance networks and specifically the submarine cable market. They provide information on 368 submarine cables starting in 1989. The information reported includes the cable's profile, name, year when it was ready for service, length, owners, and geographical coordinates of its landing points.[17]

IV. Basic Results

We estimate equation (1), where foreign exchange returns are regressed on the surprise component of U.S. macroeconomic announcements, using a pooled OLS estimator.[18] Basic results are in Table 1. The standard errors are robust to heteroskedasticity and clustered by currency. Estimates for the full sample are in columns (1) to (3); those for G10 currencies in columns (4) to (6); and those for non-G10 currencies in columns (7) to (9).[19] The estimates in columns (1), (4) and (7) include all observations; those in columns (2), (5) and (8) are restricted to days with news announcements; and those in columns (3), (6) and (9) include time and currency-fixed effects.

The estimates in column 1 are consistent with those of Andersen et al. (2003). Positive U.S. news on policy interest rates, unemployment and the trade balance leads to appreciation of the dollar against local currencies, as expected.[20] That higher interest rates cause the dollar to appreciate is consistent with the numerous studies which, after Fama (1984), have documented the existence of a forward bias puzzle. A one-standard deviation positive news shock to U.S.

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

[17] That we have annual data for inauguration of cables and daily data for exchange rates is not a source of concern because identification of the effect of cables in the year of inauguration might be noisier. Our estimates will be dominated by the data for the other 17 other years of the sample, when there is no comparable source of noise.

[18] We use OLS in our baseline specification after having experimented with fixed and random effects estimators; those panel-level effects were statistically insignificant from zero, consistently with the efficient market hypothesis.

[19] The G10 currencies are the ten most heavily traded currencies in the foreign exchange market. They include the U.S. dollar, euro, yen, sterling, Swiss franc, Canadian dollar, Australian dollar, New Zealand dollar, Swedish Krona and Norwegian Krone.

[20] The effect of output-related (i.e., GDP and industrial production) news is statistically insignificant in the full-sample estimates, however, while that of CPI news is negative. To make the sign of the estimated coefficient on unemployment rate news comparable with that of the other news, we multiplied unemployment rate news by minus one.

policy interest rates leads on average to a 0.07 percent appreciation of the dollar against local currencies, which is essentially the same as that of Andersen et al.[21] The results are similar when the sample is limited to days with news announcements (see column 2); when controlling for fixed and time effects (see column 3); and when restricted to G10 currencies (columns 4 to 6) or non-G10 currencies (see columns 7 to 9), although the magnitude of the coefficient varies across country groups.

In the case of G10 currencies, news suggesting more vigorous U.S. economic activity (higher industrial production and lower unemployment) is good for the dollar.[22] As Andersen et al. observe, this is consistent with various models of exchange rate determination, including simple monetary models (e.g., Mark 1995) and more sophisticated frameworks including a U.S. central bank reaction function (e.g., Taylor 1993). Note however that we obtain lower R^2s, in line with differences in data frequency between our sample and theirs.[23]

Insofar as our sample covers 20 years, it might be argued that the response of exchange rates to news varies over time due to unobserved global factors. For instance, it could be argued that the move to the zero lower bound by the Federal Reserve and other major central banks after the global financial crisis of 2008 reduced the reaction of exchange rates to macroeconomic news (see e.g., Swanson and Williamson, 2014).[24] This possibility is pursued in columns (3), (6) and (9) of Table 1 which report estimates controlling for time (and fixed) effects. Our findings remain essentially unchanged, which suggests that despite the federal funds rate being essentially zero since December 2008 (along with the policy rates of certain other central banks), exchange rates have responded to news in much the same way.[25]

Table 2 reports estimates of equation (2) where foreign exchange returns are regressed on the surprise component of U.S. macroeconomic announcements and also on the presence of fiber-optic cable connections, entered on their own and interactively with the news variable. The

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[21] Their estimate was 0.05% for sterling/dollar and yen/dollar, against 0.07% for deutsche mark/dollar and Swiss franc/dollar (see Andersen et al. 2003, p. 51).

[22] Readers will remember that the sign of the unemployment rate variable is flipped.

[23] In other words daily data for our sample against 5-minute intraday data for their sample. Insofar as the bulk of news effects are observed in the minutes after their announcement, other factors may add to the variability of exchange rates over the rest of the day.

[24] It could similarly be argued (as in Borio et al. 2016) that tighter limits to arbitrage since the global financial crisis have led to violations of covered interest parity and contributed to disconnect exchange rates from interest rates.

[25] This echoes Swanson and Williams (2014), whose estimates suggest that the response to macroeconomic news of the dollar-sterling and dollar-euro exchange rates remained largely unchanged during the zero-lower-bound period.

estimates for the full sample are reported in column (1); those for G10 currencies in column (2); and those for non-G10 currencies in column (3).

Currencies of countries connected to EBS and Thomson Reuters matching servers by fiber-optic cables react less to U.S. economic news than the currencies of countries that are not so connected (e.g., in the full sample estimates in column 1 of Table 2 for unemployment rate news and in the estimates restricted to non-G10 currencies in column 3 of Table 2 for policy interest rate news). A one-standard deviation positive news shock to U.S. policy interest rates leads to an almost 0.07 percent appreciation of the dollar against the currencies of non-G10 countries that are not so connected. The same shock leads to an appreciation of the dollar by about 0.04 percent against the currencies of countries that are connected via fiber-optic cables, a response that is about 50 percent smaller.

Figure 3 shows the predicted exchange rate response of non-G10 currencies to US monetary policy news with (grey line) and without (black line) submarine fiber-optic cable connections, derived from the estimates reported in column 3 of Table 2. 90 percent confidence intervals are shown as dashed lines. It is evident that a cable connection attenuates the effect of news on exchange rates, due to the fact that the grey line (with cables) is significantly flatter than the black line (without cables).This is consistent with the “thick-skinned” view that ICT helps to level the informational playing field across investors by easing access to information other than public signals extracted from observed prices and that it therefore tends to limit trend-following behavior.[26] In robustness checks we controlled for fixed and time effects and obtained the same results, which again suggests that our findings are not affected by unobserved global factors.[27]

V. Extended Specification and Results

The foreign exchange market is dominated by trading in a few major financial centers such as New York, London, Tokyo, Hong Kong, and Singapore (see e.g., McCauley and Scatigna 2011 and Rime and Schrimpf 2013). Some currencies are traded mostly offshore (i.e., outside of their country of issuance), while others are traded mainly onshore.

[26] These findings are also in the spirit of recent studies such as Brogaard et al. (2015) finding limited evidence that high-frequency traders cause extreme price movements, insofar as they rather provide liquidity and absorb imbalances from slower traders in extreme price movements episodes.

[27] The estimates are not reported here to save space but are available from the authors upon request.

Fiber-optic submarine cables play into these patterns. They connect two points that are geographically distant, and the greater the distance, the greater the latency time (the longer it takes to receive information and to complete an electronic trade). It follows that distance may have differentiated impacts conditional on the location of investors. These observations are consistent with theoretical analyses suggesting that domestic (onshore) and foreign (offshore) traders can have different interpretations of the same news (see e.g., Osambela 2013, 2015; Dumas, Lewis and Osambela 2015).

This matters because the informational gains from access to a large-bandwidth-high-speed internet connection may differ depending on the source of news. Consider the impact of U.S. news on currency units that are traded mainly offshore (offshore meaning not in the country where the currency is issued but in international financial centers like New York, London or Tokyo). Traders in New York are located in the country where the news in question is emitted and should therefore enjoy an informational advantage even in the absence of a cable connection. Traders in other large financial centers such as London and Tokyo may enjoy an information advantage over traders in smaller centers even in the absence of a cable connection.[28] It follows that there is no reason why currencies traded in large financial centers should react less to news originating in the centers in question following the activation of cable connections with other countries.

Similarly, consider currencies that are traded mainly onshore (in the issuing country). The transmission of U.S. news to these other markets may be significantly enhanced by large-bandwidth-high-speed internet connections. Traders will be able to better access and trade on information produced by dealers, banks, consultancies and research organizations in financial centers like New York. The result should be less trend-following behavior and more muted reactions to U.S. news.

To distinguish these effects, we estimate a model including direct and interacted effects of news; large-bandwidth-high-speed internet connectivity (cable connection vs. no cable connection); and location of foreign exchange trading (onshore vs. offshore):

[28] For instance, they may have access to proprietary data bases or in-house research resulting in significant economies of scale and scope. Or they may benefit from a larger customer base and better access to private information about order flows, which may also help them forecast and exploit the future trading interests of smaller traders (Hau 2001; Moore and Payne 2011).

$$r_{j,t} = \alpha_j + \sum_{k \in I} \beta^k S_t^k + \gamma_c \, Cables_{j,t} + \gamma_o \, Offshore_{j,t} + \sum_{k \in I} [\delta^k S_t^k \times Cables_{j,t}] + \sum_{k \in I} [\mu^k S_t^k \times Offshore_{j,t}] + \sum_{k \in I} [\rho^k S_t^k \times Cables_{j,t} \times Offshore_{j,t}] + \varepsilon_{j,t}, \quad (3)$$

where $Offshore_{j,t}$ is a dummy equaling one if the share of trading occurring offshore for currency *j* in period *t* is above the full sample median and zero otherwise.

Data on the location of foreign exchange trading were obtained from Bank for International Settlements (BIS) estimates of onshore, offshore and global foreign exchange turnover by currency. We have data for 55 currencies (including 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. 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. 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. 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.[29]

Figure 4 shows the evolution between 1995 and 2013 of the unweighted averages of foreign exchange trading occurring offshore for selected currency groups, namely the relatively-liquid G10 currencies, non-G10 currencies, and all currencies in our sample. Evidently, there is significant heterogeneity across space and time in the extent of foreign exchange trading occurring offshore.

We include both direct effects and interactions to take into account where news is emitted, where it is received, and whether the country is point-to-point connected to the matching servers of EBS and Reuters.

[29] We obtain annual data from the BIS triennial survey data using linear interpolation and use the annual estimates to fill in values for daily observations.

Extensions of the “thin” vs. “thick-skinned” hypotheses conditional on trading location are that:

$$H_0\colon \left|E\left[r_{j,t}\middle|News, Onshore = 1, Cables = 1\right]\right| \leq \left|E\left[r_{j,t}\middle|News, Onshore = 1, Cables = 0\right]\right|$$

where rejecting H_0 is evidence against the “thick-skinned” hypothesis, and

$$H_0\colon \left|E\left[r_{j,t}\middle|News, Onshore = 1, Cables = 1\right]\right| > \left|E\left[r_{j,t}\middle|News, Onshore = 1\ Cables = 0\right]\right|$$

where rejecting H_0 is evidence in favor against the “thin-skinned” hypothesis.

To keep the discussion tractable, we focus our estimates of Equation (3) on monetary policy news (see below for a discussion of other types of news). Conditioning on trading location provides a test of validity of our identification strategy: the effect of technology picked up by cable connections should be significant only for currencies traded mainly onshore, not those traded mainly offshore.

In Table 3 the full sample estimates are in column (1); those in column (2) are restricted to days with macroeconomic announcements; those in column (3) exclude outliers in foreign exchange returns, while those in column (4) exclude outliers in news surprises; time and fixed currency-effects are included in the estimates of column (5), while those of column (6) exclude the U.K. and Japan.[30]

The estimates again suggest that ICT dampens the reaction of exchange rates to news, presumably by easing access to information other than publicly observed prices, and that it thereby weakens the incentive for trend-following behavior. This is illustrated in Figure 5, which shows the predicted exchange rate response to U.S. monetary policy news of currencies that are heavily traded onshore (left-hand-side panel) and offshore (right-hand-side panel) with (grey line) and without (black line) submarine fiber-optic cable connections. The figures use the

[30] The U.K. and Japan are excluded in order to check whether the estimates are sensitive to the inclusion of the non-U.S. major financial centers.

estimates reported in column 1 of Table 3.[31] 90 percent-confidence intervals are shown as dashed lines.

The effect of a cable connection on the response to news is significantly larger for currencies traded mainly traded onshore. This is evident from the fact that the grey line (with cables) is flatter than the black line (without cables). A one-standard deviation positive news shock to U.S. policy interest rates leads to a 0.10 percent appreciation of the dollar against the currencies of countries that are not connected by cable and are mainly traded onshore. By comparison, the same shock leads to an appreciation of the dollar of only 0.02 percent against the currencies of countries mainly traded onshore that are connected to fiber-optic cables – a response that is 80 percent smaller. Intuitively, large-bandwidth-high-speed internet connections enable traders onshore to access and trade on U.S. news and on related analysis produced by dealers, banks, consultancies and research firms located in major financial centers. Better informed traders have less of a tendency to follow and amplify market trends by focusing exclusively on actual or past returns to anticipate future returns, consistent with the "thick-skinned" hypothesis.

For currencies mainly traded offshore in financial centers like New York, London and Tokyo differences in the effects with and without cable connections are insignificant (see the right-hand-side panel of Figure 5). This is plausible insofar as U.S. news is available to traders in the major offshore financial centers even in the absence of cable connections, in line again with the "thick-skinned" hypothesis. Controlling for outliers, as in columns (3) and (4); for time and fixed effects (as in column (5); and excluding the U.K. or Japan from the sample leaves our results essentially unaltered.

Table 4 reports full sample estimates for the other types of news (GDP, industrial production, CPI, the unemployment rate, and the trade balance). The results are varied. This is consistent with the results in Table 1 above, which suggested that some pieces of news matter more for exchange rates than others. It suggests that the information-enhancing effects of technological improvements are mainly concentrated on focal policy announcements, like those concerning monetary policy, which have long been emphasized in analytical work on exchange rate determination (see e.g., Fatum and Scholnick 2008). It is consistent with casual impression that foreign exchange traders focus in particular on monetary policy announcements.

[31] Figures based on the estimates in other columns are broadly similar.

That said, a number of patterns are similar across countries. Where a piece of U.S. news has a positive effect on the exchange rate, that positive effect is uniformly dampened by the presence of a cable connection. This dampening effect tends to be attenuated when the currency in question is traded mainly offshore (in major financial centers like New York, London or Tokyo), where according to our interpretation the presence of a cable connection should not matter or should matter less. This last set of effects is not always statistically significant, consistent with the earlier finding that not all types of macroeconomic news are equally significant for exchange rate movements. But the basic pattern of coefficients for other variables is not inconsistent with what we find for monetary policy news.

Next we consider potential asymmetries, and specifically whether the effect of cable connections varies with the sign of the news. We compare estimates based on a restricted sample of observations with negative interest rate policy news, versus estimates restricted to positive news.[32] The estimates on the two samples are indistinguishable from one another, suggesting an absence of significant asymmetries. We examine whether the effect of cable connections varies with market uncertainty. To this end we compare estimates based on a restricted sample of observations for which the VIX index was in the top quartile of its distribution, versus estimates based on a sample also using the remaining observations.[33] While the coefficients obtained from the two sets of estimates were somewhat different, the patterns were the same; they were consistent, as before, with the "thick-skinned" hypothesis insofar as cable connections dampened the effect of interest rate policy news for currencies mainly traded onshore.

Our baseline estimates do not control for the effect of local news. This issue is taken up in Table 5, where we again focus on Equation (3) for monetary-policy news. We estimate that relationship using a range of different subsamples. The full sample estimates are in column (1); those in column (2) are restricted to days with macroeconomic announcements; those in column (3) exclude outliers in foreign exchange returns, while those in column (4) exclude outliers in news surprises; time and fixed currency-effects are included in the estimates of column (5), while those of column (6) exclude the U.K. and Japan.

The results again suggest that ICT dampens the reaction of exchange rates to news, presumably by easing access to information other than publicly observed prices and disincentivizing trend-

[32] The estimates are not reported here to save space but are available from the authors upon request.

[33] The estimates are not reported here to save space but are available from the authors on request. The VIX is an index of implied volatility on call options written on the S&P 500, which is often used by market participants as a metric of market-wide uncertainty.

following behavior. The effect is large for currencies traded mainly onshore; this is true for both local and global news. A one-standard deviation positive news shock to U.S. policy interest rates leads to a 0.10 percent appreciation of the dollar against the currencies of countries that are not connected by cable and are mainly traded onshore. By comparison, the same shock leads to an appreciation of the dollar of only 0.02 percent against the currencies of countries mainly traded onshore that are connected to fiber-optic cables – a response that is 80 percent smaller.

Intuitively, high-speed internet connections enable onshore traders to access and act on U.S. news which is of global importance. They enable such traders to access and act on analysis of that news produced by dealers, banks, consultancies and research firms located in major financial centers. It would appear that better informed traders have less of a tendency to follow and amplify market trends by focusing exclusively on actual or past returns to anticipate future returns, in line with the "thick-skinned" hypothesis.

Similarly, a one-standard deviation positive news shock to local policy interest rates is associated with a 0.12 percent depreciation of the dollar against the currencies of countries that are not cable connected and traded mainly onshore. In contrast, the same shock leads to just a 0.02 percent depreciation of the dollar against the currencies of countries mainly traded onshore that are connected to fiber-optic cables – a response that is roughly 85 percent smaller.

That currencies traded mainly in the issuing country react less to local news following the establishment of a cable connection suggests that someone, presumably foreign traders located in financial centers like New York, London or Tokyo are better able to assimilate and process news about the country in question once the cable connection is established. This could be because foreign traders now have better access to information produced by local banks, consultancies and research organizations, causing them in turn to engage in less trend-following behavior.

For currencies traded mainly offshore in major financial centers like New York, London or Tokyo differences in the impact of global news are insignificantly different in the presence and absence of cable connections. This is plausible insofar as global news is available to traders in the major offshore financial centers even in the absence of cable connections. The estimated response of currencies traded mainly offshore (e.g., in New York) to local (non-U.S.) news seems slightly stronger with cable connections than without, although the effect is economically small. This is a qualification to our overall conclusion that the data support the “thick-skinned” hypothesis over the “thin-skinned” hypothesis.

VI. CONCLUSION

We have analyzed the impact of information technology on how financial markets respond to news, focusing on the foreign exchange market as a case study. We identify changes in technology by the connection of countries to the submarine fiber-optic cables used for electronic trading. These cable connections were laid for reasons unrelated to foreign exchange transactions and can therefore be taken as exogenous for present purposes.

We find that cable connections dampen the response to macroeconomic news. Currencies respond less sharply to news emitted in the issuing country or in foreign countries like the United States when the currencies in question are traded mainly onshore in the issuing country. This is consistent with the view that technology levels the informational playing field by easing access to information other than public signals extracted from observed prices and that it thereby reduces trend-following behavior. Our estimates suggest that cable connections reduce the reaction of exchange rates to monetary policy news by 50 to 80 percent.

A variety of ideas have been floated for limiting the volatility of exchange rates and asset prices more generally and reducing the alleged contribution of the high-speed trading facilitated by twenty-first century information and communications technology in particular. Such ideas include speed bumps, taxes and outright bans on algorithmic trading. Our results do not speak to the merits and demerits of such proposals. But they do suggest that the wider and more comprehensive provision of information may have a dampening effect on volatility

Table 1: Impact of Macro News on Exchange Rates

	(1) All: All days	(2) All: News days	(3) All: Fixed & time effects	(4) G10: All days	(5) G10: News days	(6) G10: Fixed & time effects	(7) Non-G10: All days	(8) Non-G10: News days	(9) Non-G10: Fixed & time effects
Policy interest rate	0.068***	0.066***	0.069***	0.145***	0.144***	0.146***	0.050***	0.048***	0.051***
	(0.010)	(0.009)	(0.010)	(0.023)	(0.022)	(0.023)	(0.008)	(0.008)	(0.008)
GDP	-0.003	-0.005	0.000	-0.009	-0.010	-0.003	-0.002	-0.004	0.001
	(0.008)	(0.008)	(0.008)	(0.013)	(0.013)	(0.012)	(0.010)	(0.010)	(0.010)
Industrial production	-0.041	-0.039	-0.039	0.096***	0.096***	0.098***	-0.071	-0.070	-0.070
	(0.074)	(0.074)	(0.074)	(0.019)	(0.018)	(0.018)	(0.090)	(0.090)	(0.090)
Consumer price index	-0.015***	-0.014**	-0.016***	-0.027+	-0.027	-0.028+	-0.013**	-0.012**	-0.013**
	(0.006)	(0.006)	(0.006)	(0.019)	(0.019)	(0.019)	(0.005)	(0.005)	(0.005)
Unemployment rate	0.031***	0.036***	0.032***	0.077***	0.080***	0.080***	0.021***	0.026***	0.021***
	(0.007)	(0.008)	(0.007)	(0.016)	(0.015)	(0.016)	(0.007)	(0.008)	(0.007)
Trade balance	0.015+	0.015+	0.016+	0.054***	0.054***	0.057***	0.006	0.006	0.007
	(0.011)	(0.011)	(0.011)	(0.012)	(0.012)	(0.012)	(0.013)	(0.013)	(0.013)
Constant	0.010***	-0.016+	0.045***	0.001	-0.014*	0.038***	0.012***	-0.017	0.042***
	(0.003)	(0.011)	(0.009)	(0.001)	(0.008)	(0.008)	(0.004)	(0.015)	(0.010)
Observations	240,430	62,014	240,430	43,875	13,391	43,875	196,555	48,623	196,555
R^2	0.000	0.000	0.001	0.003	0.009	0.006	0.000	0.000	0.001

Source: Authors' calculations.

Note: The table reports estimates of model equation (1) where foreign exchange returns are regressed on the surprise component of U.S. macroeconomic announcements. Estimates for the full sample are reported in columns (1) to (3); those for G10 currencies in columns (4) to (6); and those for non-G10 currencies in columns (7) to (9). The estimates in columns (1), (4) and (7) include all observations; those in columns (2), (5) and (8) are restricted to days with macroeconomic news; and those in columns (3), (6) and (9) include time and currency-fixed effects. *** $p<0.01$, ** $p<0.05$, * $p<0.1$, $^{+}$ $p<0.2$.

Table 2: Impact of Macro News on Exchange Rates – Role of Technology

	(1) All	(2) G10	(3) Non-G10
Policy interest rate	0.080***	0.138***	0.071***
	(0.012)	(0.012)	(0.013)
GDP	0.002	-0.002	0.003
	(0.016)	(0.028)	(0.018)
Industrial production	-0.137	0.134***	-0.177
	(0.189)	(0.028)	(0.216)
Consumer price index	-0.013+	-0.044	-0.009
	(0.009)	(0.032)	(0.008)
Unemployment rate	0.052***	0.116***	0.043***
	(0.013)	(0.019)	(0.013)
Trade balance	0.012	0.071***	0.003
	(0.028)	(0.010)	(0.031)
Cables × policy interest rate	-0.018	0.010	-0.035**
	(0.018)	(0.032)	(0.017)
Cables × GDP	-0.009	-0.009	-0.008
	(0.019)	(0.033)	(0.021)
Cables × industrial production	0.157	-0.053+	0.180
	(0.190)	(0.033)	(0.216)
Cables × consumer price index	-0.003	0.022	-0.006
	(0.011)	(0.039)	(0.010)
Cables × unemployment rate	-0.034**	-0.053**	-0.036**
	(0.016)	(0.019)	(0.016)
Cables × trade balance	0.005	-0.022	0.005
	(0.029)	(0.018)	(0.032)
Cables	0.001	-0.006	0.003
	(0.007)	(0.006)	(0.009)
Constant	0.009	0.006	0.010
	(0.007)	(0.006)	(0.008)
Observations	240,430	43,875	196,555
R^2	0.000	0.003	0.000

Source: Authors' calculations

Note: The table reports estimates of model equation (2) where foreign exchange returns are regressed on the surprise component of U.S. macroeconomic announcements as well as on the direct and interacted effect of fiber-optic cable connections. The estimates for the full sample are reported in column (1); those for G10 units in column (2); and those for non-G10 units in column (3). *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p<0.2.

Table 3: Impact of Monetary Policy News on Exchange Rates – Role of Trading Location and Technology

	(1) All	(2) News days	(3) Ex. outliers in FX returns	(4) Ex. outliers in news surprises	(5) Time & fixed effects	(6) Ex. UK/JP
Policy interest rate	0.097***	0.095***	0.097***	0.097***	0.098***	0.097***
	(0.033)	(0.032)	(0.033)	(0.033)	(0.033)	(0.033)
Offshore	-0.004	-0.003	-0.004	-0.004	-0.007	-0.004
	(0.004)	(0.009)	(0.004)	(0.004)	(0.007)	(0.004)
Cables	-0.003	-0.006	-0.004	-0.003	-0.007	-0.003
	(0.004)	(0.008)	(0.003)	(0.004)	(0.011)	(0.004)
Offshore × policy interest rate	0.040	0.040	0.040	0.040	0.039	0.040
	(0.046)	(0.046)	(0.046)	(0.046)	(0.047)	(0.046)
Cables × policy interest rate	-0.078**	-0.078**	-0.078**	-0.078**	-0.078**	-0.081**
	(0.037)	(0.037)	(0.037)	(0.037)	(0.038)	(0.038)
Cables × offshore × policy interest rate	0.080+	0.079+	0.080+	0.080+	0.081+	0.091+
	(0.059)	(0.059)	(0.059)	(0.059)	(0.059)	(0.060)
Constant	0.012***	-0.005	0.012***	0.012***	0.042***	0.012***
	(0.004)	(0.010)	(0.004)	(0.004)	(0.007)	(0.004)
Observations	180,409	50,073	180,407	180,384	180,409	170,543
R^2	0.001	0.002	0.001	0.001	0.002	0.001

Source: Authors' calculations.

Note: The table reports estimates of model equation (3) where foreign exchange returns are regressed on the surprise component of U.S. policy interest rate announcements as well as on the interacted effect of offshore foreign exchange trading and point-to-point submarine fiber-optic cable connections to EBS and Reuters matching servers in New York, London and Tokyo. The full sample estimates are reported in column (1); those in column (2) are restricted to days with macroeconomic announcements; those in column (3) exclude outliers in foreign exchange returns, while those in column (4) exclude outliers in news surprises; time and fixed currency-effects are included in the estimates of column (5), while those of column (6) exclude the U.K. and Japan. *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p<0.2.

Table 4: Impact of Other News on Exchange Rates – Role of Trading Location and Technology

	(1) Policy rate interest rate (G10)	(2) Policy rate interest rate (Non-G10)	(3) GDP	(4) IPI	(5) CPI	(6) Unemployment rate	(7) Trade balance
U.S. news	0.097***	0.097***	0.045+	0.067***	0.006	0.064***	0.046*
	(0.034)	(0.001)	(0.033)	(0.022)	(0.011)	(0.021)	(0.026)
Offshore	0.001	-0.014*	-0.004	-0.004	-0.004	-0.004	-0.004
	(0.005)	(0.007)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Cables	-0.002	-0.007+	-0.003	-0.003	-0.003	-0.003	-0.003
	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Offshore × U.S. news	0.040	0.040**	-0.038	0.005	-0.020	0.011	-0.006
	(0.062)	(0.014)	(0.034)	(0.031)	(0.023)	(0.028)	(0.026)
Cables × U.S. news	-0.081**	-0.027***	-0.061*	-0.054**	-0.022+	-0.039+	-0.027
	(0.039)	(0.001)	(0.035)	(0.024)	(0.015)	(0.025)	(0.028)
Cables × offshore × U.S. news	0.055	0.051+	0.056+	0.021	0.024	-0.014	0.004
	(0.083)	(0.035)	(0.040)	(0.038)	(0.028)	(0.034)	(0.029)
Constant	0.011**	0.018**	0.012***	0.012***	0.012***	0.011***	0.012***
	(0.004)	(0.007)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Observations	137,054	43,355	180,409	180,409	180,409	180,409	180,409
R^2	0.000	0.001	0.000	0.000	0.000	0.000	0.000

Source: Authors' calculations

Note: The table reports full sample estimates of model equation (3) where foreign exchange returns are regressed on the surprise component of U.S. macro announcements as well as on the interacted effect of offshore foreign exchange trading and point-to-point submarine fiber-optic cable connections to EBS and Reuters matching servers in New York, London and Tokyo. *** $p<0.01$, ** $p<0.05$, * $p<0.1$, $^{+}$ $p<0.2$.

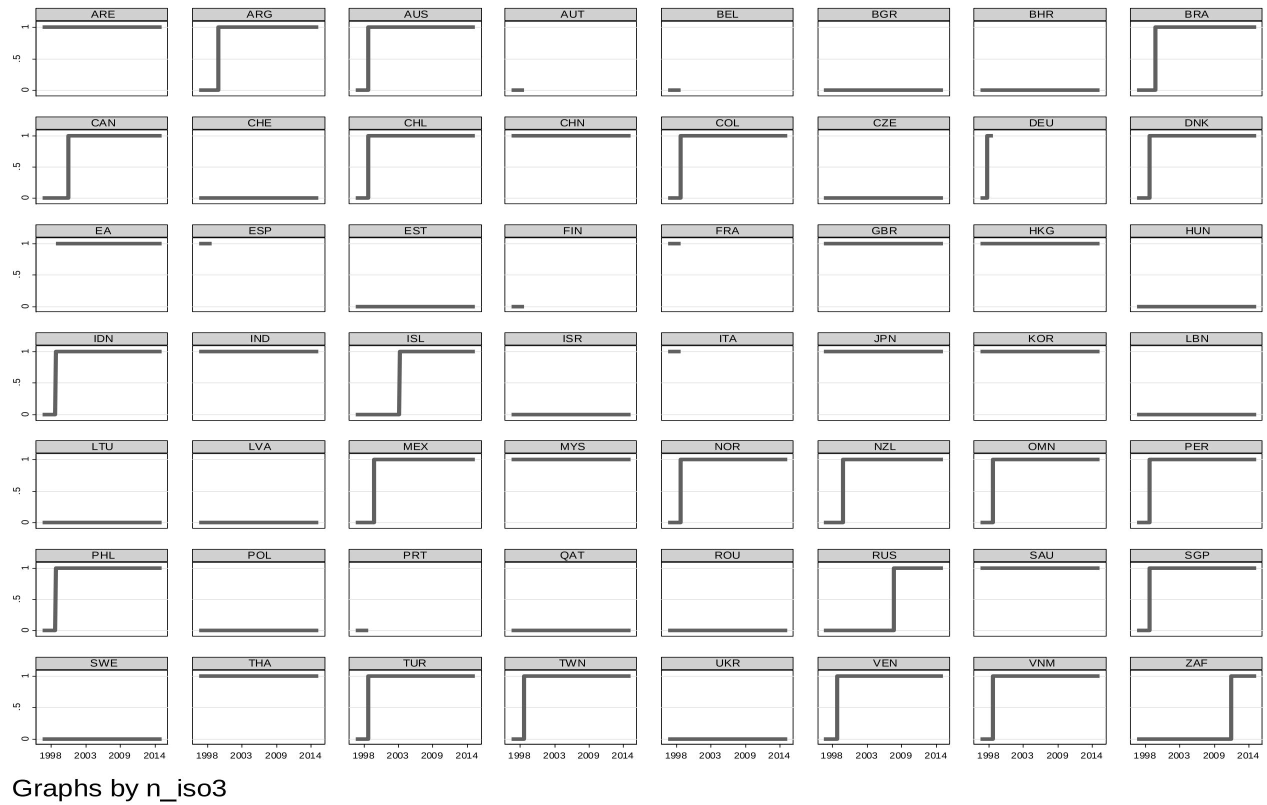
Table 5: Estimates Controlling for the Effect of Local News

	(1) All	(2) News days	(3) Ex. outliers in FX returns	(4) Ex. outliers in news surprises	(5) Time & fixed effects	(6) Ex. UK/JP
Local policy interest rate	-0.122*	-0.123*	-0.122*	-0.122*	-0.122*	-0.122*
	(0.072)	(0.071)	(0.072)	(0.072)	(0.071)	(0.072)
U.S. policy interest rate	0.097***	0.095***	0.097***	0.097***	0.098***	0.097***
	(0.033)	(0.032)	(0.033)	(0.033)	(0.033)	(0.033)
Offshore	-0.004	-0.003	-0.004	-0.004	-0.007	-0.004
	(0.004)	(0.009)	(0.004)	(0.004)	(0.007)	(0.004)
Cables	-0.003	-0.006	-0.004	-0.003	-0.007	-0.003
	(0.004)	(0.008)	(0.003)	(0.004)	(0.011)	(0.004)
Offshore × local policy interest rate	0.103	0.103	0.103	-0.012	0.104	0.103
	(0.114)	(0.113)	(0.114)	(0.107)	(0.113)	(0.114)
Cables × local policy interest rate	0.106+	0.106+	0.106+	0.128+	0.106+	0.139*
	(0.081)	(0.080)	(0.081)	(0.081)	(0.080)	(0.082)
Offshore × U.S. policy interest rate	0.040	0.040	0.040	0.040	0.039	0.040
	(0.046)	(0.046)	(0.046)	(0.046)	(0.047)	(0.046)
Cables × U.S. policy interest rate	-0.078**	-0.078**	-0.078**	-0.078**	-0.078**	-0.081**
	(0.037)	(0.037)	(0.037)	(0.037)	(0.038)	(0.038)
Cables × offshore × local policy interest rate	-0.164+	-0.164+	-0.164+	-0.113	-0.164+	-0.195+
	(0.123)	(0.123)	(0.123)	(0.120)	(0.123)	(0.124)
Cables × offshore × U.S. policy interest rate	0.080+	0.079+	0.080+	0.080+	0.081+	0.091+
	(0.059)	(0.059)	(0.059)	(0.059)	(0.059)	(0.060)
Constant	0.012***	-0.005	0.012***	0.012***	0.042***	0.012***
	(0.004)	(0.010)	(0.004)	(0.004)	(0.007)	(0.004)
Observations	180,409	50,073	180,407	180,384	180,409	170,543
R^2	0.001	0.002	0.001	0.001	0.002	0.001

Source: Authors' calculations.

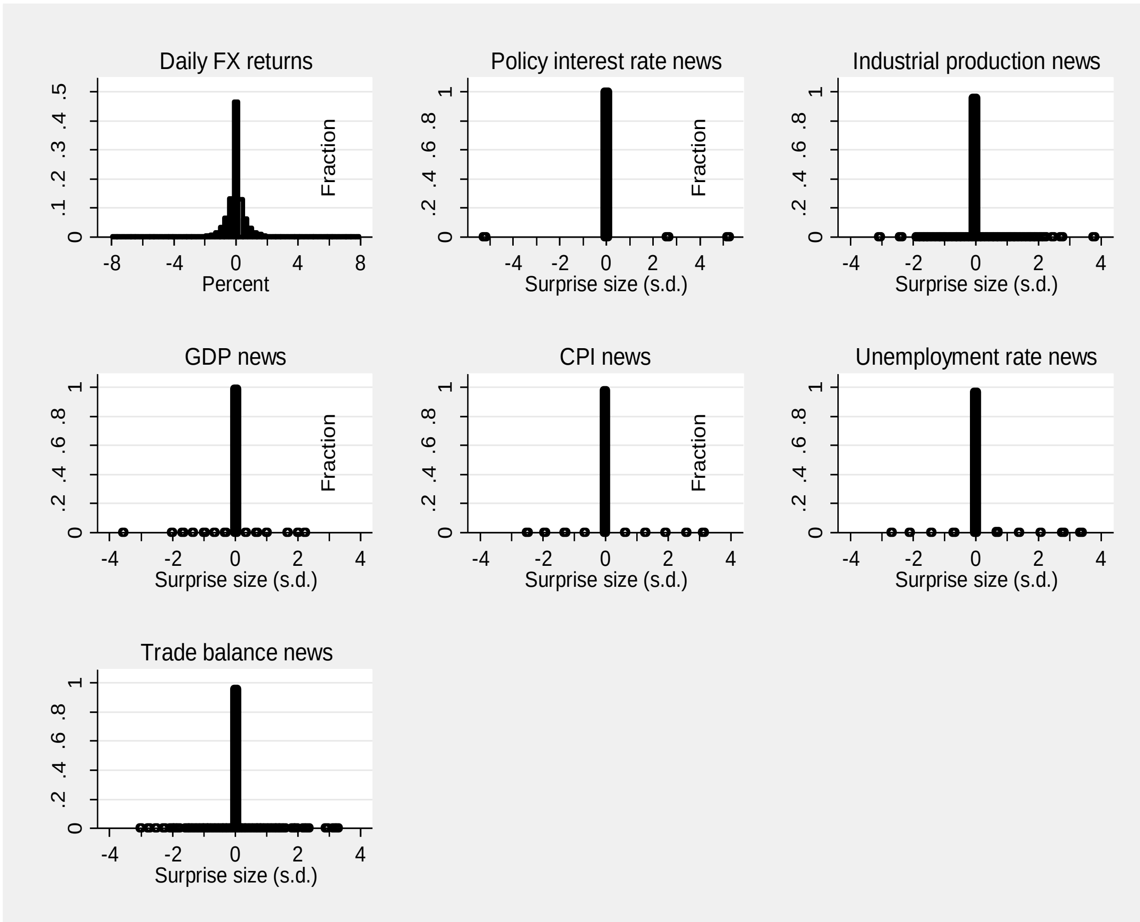
Note: The table reports full sample estimates of model equation (3) where foreign exchange returns are regressed on the surprise component of local and U.S. monetary policy announcements as well as on the interacted effect of offshore foreign exchange trading and point-to-point submarine fiber-optic cable connections to EBS and Reuters matching servers in New York, London, and Tokyo. *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ p<0.2.

Figure 1: Point-to-Point Connection to the World's Largest Foreign Exchange Markets via Submarine Fiber-Optic Cables



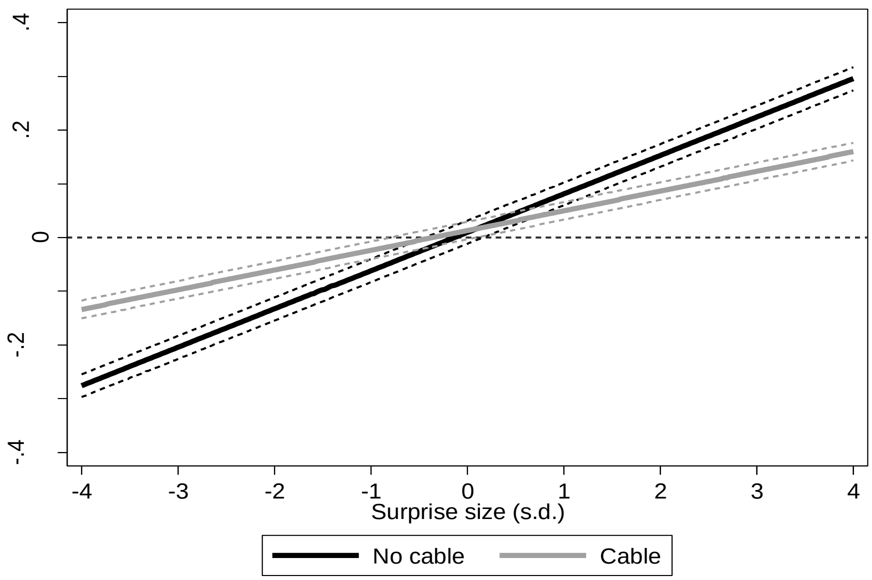
Source: Authors' calculations.
Note: This figure shows the evolution of the connectivity of the 56 countries of our sample to the network of submarine fiber-optic cables using a dummy variable which takes a value of one if a country is point-to-point connected via a submarine fiber-optic cable to the world's three largest foreign exchange markets (the U.S., the U.K. and Japan) and zero otherwise.

Figure 2: Distribution of Daily FX Returns and Macroeconomic News



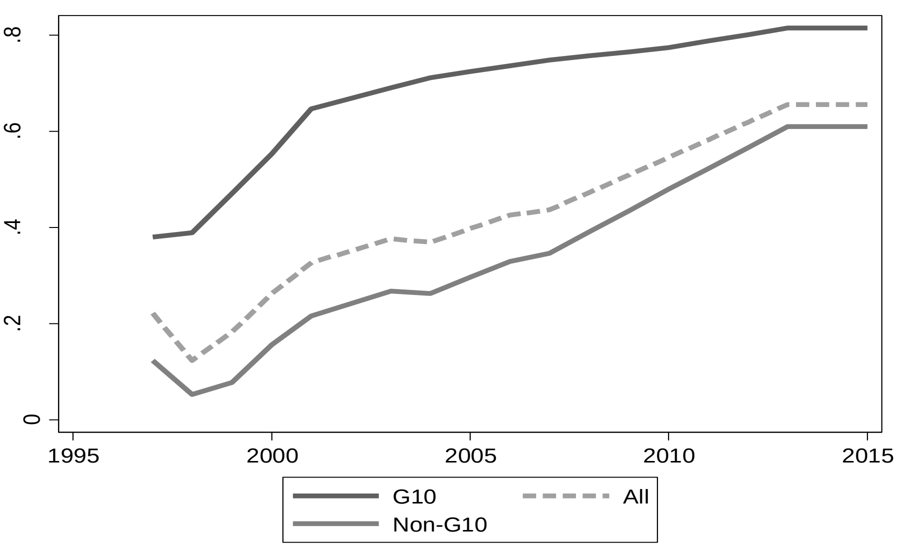
Source: Authors' calculations.
Note: The figure shows the distribution of exchange rate returns (in percent) as well as of standardized macroeconomic news (in standard deviations) for the full sample of observations.

Figure 3: Conditional Impact of Monetary Policy News on Exchange Rates – Role of Technology



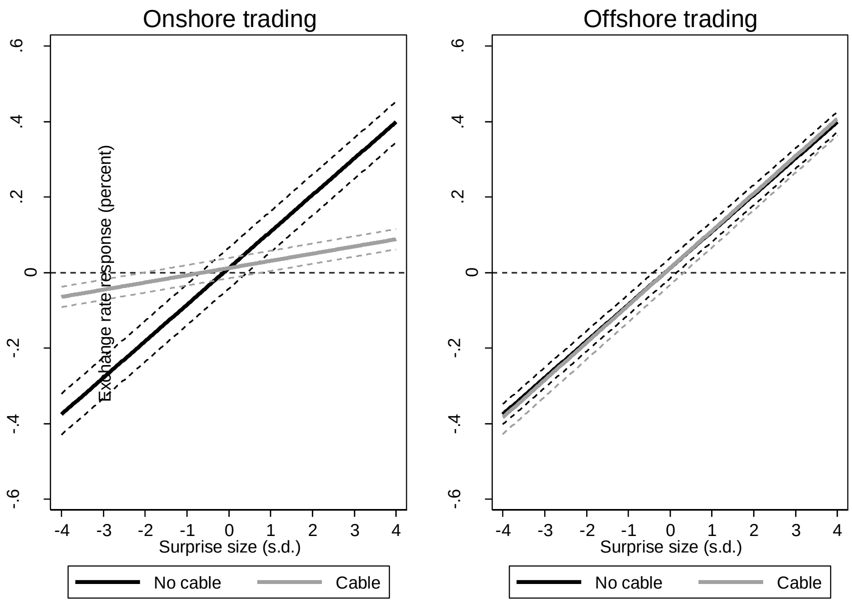
Source: Authors' calculations.
Note: This figure shows the predicted exchange rate response of non-G10 currencies to US monetary policy news with (grey line) and without (black line) submarine fiber-optic cable connection. The figure is based on the estimates reported in column 3 of Table 2. 90%-confidence intervals are shown as dashed lines.

Figure 4: Share of Foreign Exchange Trading Occurring Offshore



Source: Authors' calculations.
Note: This figure shows the evolution between 1995 and 2013 of the un-weighted averages of foreign exchange trading occurring offshore for selected currency groups, namely the G10 highly-liquid units (USD, EUR, JPY, GBP, CHF, AUD, CAD, SEK, NOK), the remaining 46 units and all units of our sample.

Figure 5: Conditional Impact of U.S. Policy Interest Rate News on Exchange Rates – Role of Trading Location and Technology



Source: Authors' calculations.
Note: This figure shows the predicted exchange rate response to U.S. monetary policy news of currencies that are heavily traded onshore (left-hand-side panel) and offshore (right-hand-side panel) with (grey line) and without (black line) submarine fiber-optic cable connections. The figure is based on the estimates reported in column 1 of Table 3. 90%-confidence intervals are shown as dashed lines.

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