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Exchange Rates and Monetary Policy Uncertainty

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ABSTRACT

We document that a trading strategy that is short the U.S. dollar and long other currencies exhibits significantly larger excess returns on days with scheduled Federal Open Market Committee (FOMC) announcements. We show that these excess returns (i) are higher for currencies with higher interest rate differentials vis-à-vis the United States, (ii) increase with uncertainty about monetary policy, and (iii) increase further when the Federal Reserve adopts a policy of monetary easing. We interpret these excess returns as compensation for monetary policy uncertainty within a parsimonious model of constrained financiers who intermediate global demand for currencies.

ANNOUNCEMENTS BY THE Federal Open Market Committee (FOMC) are among the most highly anticipated events by investors around the world. These announcements, which occur regularly at prespecified dates, serve as the Federal Reserve's main channel for communicating its monetary policy decisions to the market. Given the close link between currency markets and monetary policy, it is only natural to expect that FOMC announcements can have large impacts on exchange rates. The active nature of the currency markets (with a daily turnover of over five trillion U.S. dollars) coupled with high market concentration and participants' ability to operate with high leverage ratios means that even small price movements in this market can potentially translate into economically significant effects.

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In this paper, we document that announcements by the FOMC have an economically and statistically significant impact on the excess returns of a host of different currencies vis-à-vis the U.S. dollar. By relying on high-frequency data, we document that a trading strategy that is short the U.S. dollar and long other currencies exhibits significantly larger average excess returns on days with scheduled FOMC announcements compared to all other days. We also document that the excess returns earned on announcement days (i) consist of a pre- as well as a postannouncement component, (ii) are higher for currencies with higher interest rate differentials vis-à-vis the United States, (iii) increase with market participants' uncertainty about monetary policy, and (iv) are higher when the Federal Reserve adopts a policy of monetary easing.

We interpret these findings through the lens of a parsimonious model of exchange rate determination in the spirit of Gabaix and Maggiori (2015), in which constrained financiers with short investment horizons intermediate global demand for currencies. These financiers can actively engage in currency trading, but have a downward-sloping demand for risk taking, which limits their risk-bearing capacity. Such a limit can arise for a variety of reasons, such as value-at-risk constraints or agency problems. Crucially, in addition to the "fundamental risk" in global demand for and supply of currencies, financiers in our model also face "monetary policy uncertainty" due to potential future changes in interest rates.

Using this framework, we show that an increase in uncertainty regarding future interest rates in the United States results in higher excess returns for other currencies: financiers are willing to engage in currency trading and to bear this extra risk only if they are compensated accordingly with higher returns. As such, all else equal, an increase in monetary policy uncertainty due to an upcoming FOMC announcement results in the depreciation of foreign currencies against the U.S. dollar, followed by an expected appreciation in the future. We also establish that the increase in excess returns in response to monetary policy uncertainty is higher for currencies with larger interest rate differentials vis-à-vis the United States. This is due to the fact that, even though an increase in the interest rate differential induces an exchange rate adjustment, financiers' risk-bearing constraints all but ensure that this adjustment does not offset the increase in the interest rate differential one-for-one, thus resulting in higher excess returns.

The fact that higher currency excess returns are meant to compensate financiers for the uncertainty in monetary policy means that such returns materialize irrespective of the interest rates set by the Fed upon the announcement. We thus interpret the impact of monetary policy uncertainty on currency excess returns as a "preannouncement" effect. However, the actual realization of the monetary policy shock also impacts foreign currencies' excess returns by affecting financiers' balance sheets, leading to what we call a "postannouncement" effect. Indeed, we show that our model predicts that an ex post adoption of an expansionary monetary policy (corresponding to an interest rate reduction by the Fed) further increases foreign currencies' excess returns.

We empirically study currency risk premia on announcement days by relying on 20 years of high-frequency data from 1994 to 2013 for the 10 most traded currencies. We find that, in line with our theoretical model, a simple trading strategy that is short the U.S. dollar and long the other currencies yields significantly higher returns on announcement days compared to nonannouncement days. We also document that returns earned on the eight announcement days account for a significant fraction of currencies' yearly excess returns. Notably, the large increase in average excess returns on announcement days is not accompanied by an equally large increase in realized risk, resulting in significantly higher Sharpe ratios on announcement days.

Since investors do not typically trade only in individual currencies but rather go long and short portfolios of currencies simultaneously, we also test our model's predictions for currency portfolios sorted based on the interest rate differential vis-à-vis the United States. Our empirical results indicate that excess returns earned on announcement days are larger for currency portfolios with higher interest rates, an observation consistent with our model. In particular, we find that a portfolio consisting of currencies with low interest rates earns an average daily return of 5.19 basis points (bps) during days when the Federal Reserve makes an announcement, compared to an average of −0.51 bps on all other days. This difference becomes larger (and highly statistically significant) for the portfolio consisting of high interest rate currencies, with a daily return of 14.47 bps on announcement days compared to 1.73 bps on all other days.

Our explanation for the large returns earned on announcement days is that they reflect a premium for heightened uncertainty about monetary policy. Using different proxies for monetary policy uncertainty, we find that an increase in market participants' uncertainty is indeed associated with higher returns on FOMC announcement days.

We next study the intraday pattern of returns in further detail by decomposing currency returns into their pre- and postannouncement components. To this end, we split the day into two nonoverlapping time windows that fall before and after the exact time of the announcement. We find that returns earned over both windows are larger on announcement days compared to the corresponding windows on nonannouncement days. We also test our model's prediction regarding the relationship between the returns earned during the postannouncement window and the stance of monetary policy by stratifying our sample into easing and tightening periods depending on the policy adopted by the Fed. Using a monetary policy indicator constructed from high-frequency data on various interest rate futures, we find that, in line with our model's prediction, postannouncement returns are higher when the Federal Reserve adopts an expansionary policy.

The observation that the stance of monetary policy and interest rate differentials are tightly linked to currency excess returns means that trading strategies that take these factors into account should exhibit higher returns compared to simpler strategies that do not. We leverage these observations to construct trading strategies that improve upon the simple strategy that always shorts the U.S. dollar along two dimensions. First, using the observation that postannouncement returns are lower after the adoption of a contractionary monetary policy, we reverse the simple strategy's position right after the announcement in response to a tightening, while leaving the position unchanged in response to an easing. Second, given that currency excess returns increase with the interest rate differential, we restrict this trading strategy to currencies that exhibit a positive interest rate differential vis-à-vis the United States. These adjustments do indeed result in more economically and statistically significant returns on announcement days, increasing the simple trading strategy's announcement-day returns from 10.77 bps to 20.54 bps (with a t-statistic of 4.17), together with an equally significant increase in the Sharpe ratio from 0.51 to 0.93.

We also test whether announcements by the Federal Reserve exert a unique impact on exchange rates, or whether similar patterns can be observed for other central bank announcements.[1] To test this hypothesis, we collect the exact timing of monetary policy announcements for the different countries in our sample and perform an empirical exercise similar to that outlined above by measuring the excess returns of interest rate–sorted portfolios vis-à-vis the corresponding currencies. Using data between 1998 and 2013, we find that announcements by the Bank of Japan (BoJ) lead to a pattern that is virtually identical to that of FOMC announcements. We find no significant effects for the rest of the central banks in our sample.

We conclude the paper by running a series of robustness checks. First, we repeat the analysis for truncated data to ensure that our results are not driven by outliers in the sample. Second, to overcome concerns regarding sample size, we compute small-sample standard errors through a bootstrap exercise. In another bootstrap exercise, we sample randomly from the distribution of nonannouncement-day returns to test whether we can generate returns similar in size to those observed on announcement days. These exercises support the robustness of our main empirical findings. We also show that announcement-day returns remain significant and highly profitable (with annualized Sharpe ratios of up to 0.8) even when transaction costs are taken into account by adjusting for bid-ask spreads. Finally, we document the unique role of monetary policy announcements on currency returns by showing that the significant difference between announcement- and nonannouncement-day returns observed for FOMC announcements is not shared by other macroeconomic announcements.

Our paper belongs to the growing literature that documents sizable responses of various asset classes to macroeconomic announcements. For instance, Hördahl, Remolona, and Valente (2015) study high-frequency movements in bond yields around macroeconomic announcements and document strong movements not only in yields but also in bond risk premia. Similarly,

[1] For instance, anecdotal evidence suggests that one of the largest one-day depreciations of the Japanese yen in recent years coincides with the BoJ's announcement of an expansion of its asset-purchase program ("Currency-trading volumes jump," *Wall Street Journal*, January 27, 2015).

Jones, Lamont, and Lumsdaine (1998) study realized bond excess returns around macroeconomic news releases about inflation and the labor market; Savor and Wilson (2013) focus on (unconditional) excess equity returns in response to inflation, labor market, and FOMC releases; Beber and Brandt (2006) use Treasury futures options to assess how the state price density changes around macroeconomic announcements; and Savor and Wilson (2014) document that systematic market risk prices risky assets (including foreign exchange portfolios) well on announcement days. Most recently, Lucca and Moench (2015) study S&P500 index returns ahead of scheduled FOMC announcements and find that announcement-day returns are due to a preannouncement drift rather than returns earned at the announcement.[2]

Even though closely related, our paper departs from this literature along several important dimensions. First, in contrast to Lucca and Moench (2015), who find that returns in the equity market are earned entirely in the 24-hour window before the announcement, we document that currency excess returns span the entire announcement day and consist of a pre- as well as a postannouncement component. Second, we find that the postannouncement returns are tightly linked to the content of the announcement, with an expansionary (contractionary) policy associated with higher (lower) returns. Finally, we provide a theoretical framework that interprets the documented pre- and postannouncement excess returns as, respectively, compensation for intermediaries' exposure to monetary policy uncertainty prior to the announcement and the ex post impact of the monetary policy shock on their balance sheets.

Our paper is also related to the theoretical asset pricing literature that studies the interaction between market frictions and exchange rates. For example, in the context of a model of the international banking system, Bruno and Shin (2015) show that local currency appreciation results in lower credit risk and hence expanded bank lending capacity. Our theoretical framework is most closely related to the recent work of Gabaix and Maggiori (2015), who present a model of exchange rate determination based on capital flows in imperfect financial markets. They show that, in the presence of intermediation frictions, shocks to financiers' risk-bearing capacity affect the level and volatility of exchange rates. Given our different focus, we depart from the framework of Gabaix and Maggiori (2015) by studying a model in which financiers may be uncertain about the future path of monetary policy and show that such uncertainty plays a first-order role in determining currency excess returns on central bank announcement days.

Finally, our paper contributes to the literature linking exchange rates to monetary policy. For example, Eichenbaum and Evans (1995), Faust and Rogers (2003), Scholl and Uhlig (2008), Rogers, Scotti, and Wright (2016), and Stavrakeva and Tang (2015), among others, study the effect of monetary policy

[2] In parallel, a large empirical literature, going back to Fleming and Remolona (1999), studies the impact of monetary policy announcements on second moments in foreign exchange markets. The main finding of this literature is that policy surprises increase realized exchange rate volatility. See Neely (2011) for a survey of this literature.

shocks extracted from high-frequency data on exchange rates in a vector autoregression framework. Different from these papers, we are mainly interested in the intradaily return patterns on announcement and nonannouncement days, with a focus on documenting the role of monetary policy in shaping these patterns.

The rest of the paper is organized as follows. In Section I, we formulate a model of exchange rate determination on central bank announcement days. Section II describes the data on which we base our analysis. Our main empirical findings are presented in Section III. Section IV concludes. All proofs and derivations are presented in the Appendix. An Internet Appendix provides additional empirical results and robustness checks.[3]

I. Theoretical Framework

In this section, we present a parsimonious model of exchange rate determination in the spirit of Gabaix and Maggiori (2015) that forms the basis of our analysis. As the main ingredient of our model, we assume that market participants are uncertain about the future stance of monetary policy prior to central bank announcements.

A. Model

Consider a discrete-time economy that lasts for three periods, $t = 0, 1, 2$. The economy consists of two countries, each populated by a unit mass of investors and with its own currency. For expositional simplicity, we refer to one of the countries as the United States and to its currency as the dollar.

Investors in each country can trade a one-period, nominal risk-free bond that is denominated in their respective domestic currency. We use R_t to denote the interest rate in the United States and R_t^* to denote the interest rate in the foreign country between periods t and $t+1$. We assume that the interest rate in the United States is smaller than that in the foreign country in all periods. The exchange rate e_t is defined as the quantity of dollars that can be bought by one unit of the foreign currency at time t.

In any given period, investors in each country have downward-sloping demand for assets denominated in the other country's currency. Such demand may arise for various reasons, such as trade or portfolio flows. We assume that U.S. investors have a time t demand of f_t/e_t for assets denominated in the foreign currency, which they fund by an offsetting position of $-f_t$ in dollars. We assume that f_t is drawn independently over time from a common continuous distribution function $G(\cdot)$ with bounded support $[\underline{f}, \bar{f}]$, where $\underline{f} > 0$. Similarly, foreign investors have a time t demand of $d_t e_t$ for dollar-denominated assets, funded by the offsetting position of $-d_t$ in their currency, where we assume that $d_t = d > 0$ is constant over time.

[3] The Internet Appendix may be found in the online version of this article.

In addition to investors, the economy is populated by a unit mass of identical risk-neutral financiers who can trade in the domestic bonds of *both* countries. As such, financiers' main role is to act as intermediaries between investors in the two countries by taking the other side of their currency demands, at a profit. The representative financier enters the market with no capital of her own and takes a time $t \in \{0, 1\}$ position of $-Q_t$ in dollars, funded by Q_t/e_t units of the foreign currency.

The representative financier unwinds this position at the end of period $t+1$. Consequently, her profit (expressed in dollars) at the end of the period is given by

$$V_{t+1} = \left(\tfrac{e_{t+1}}{e_t} R_t^* - R_t\right) Q_t, \tag{1}$$

where recall that R_t and R_t^* denote the interest rates in the United States and in the foreign country, respectively.

As our main point of departure from the framework of Gabaix and Maggiori (2015), we assume that, in addition to the "fundamental risk" in the demand and supply of currencies—captured in our model by the uncertainty in the realization of f_t—financiers also face "monetary policy uncertainty" due to potential future changes in interest rates. We model the presence of this latter kind of uncertainty by assuming that, when taking their positions at $t = 0$, financiers are uncertain about the interest rate in the United States between $t = 1$ and $t = 2$. More specifically, we assume that $\log(R_1)$ is a random variable drawn at $t = 1$ independently from (f_0, f_1, f_2) with mean $\mathbb{E}_0[\log(R_1)] = \log(R_0)$ and standard deviation σ_R.[4] Thus, σ_R serves as a natural proxy for the extent of U.S. monetary policy uncertainty. In particular, $\sigma_R > 0$ corresponds to an FOMC announcement day. On these days, market participants are uncertain about the future stance of monetary policy. In contrast, $\sigma_R = 0$ corresponds to a "normal" day with no scheduled monetary policy announcements. On such days, market participants are certain that the interest rate will remain unchanged throughout the day, in which case $R_1 = R_0$ with probability one. To simplify the derivations, we assume that the interest rate in the foreign country is deterministic and constant, that is, $R_0^* = R_1^* = R^*$. Finally, throughout the paper, we assume that the interest rate differential between the two currencies is large enough at all times, in particular, $R^* \underline{f} > R_t \overline{f}$ for $t \in \{0, 1\}$. This assumption serves as a simple sufficient condition for financiers to short the dollar in equilibrium, that is, $Q_t \geq 0$.

An immediate implication of equation (1) is that, whenever the uncovered interest rate parity (UIP) condition is not satisfied (i.e., when $\mathbb{E}_t[R_t^* e_{t+1}/e_t - R_t] \neq 0$), the representative financier wants to take infinitely large positions unless some friction limits her ability to do so. We model the presence of such intermediation frictions by assuming that the representative financier is subject

[4] The assumption that R_1 and f_t are drawn independently is made in the interest of tractability. Assessing the actual extent of comovements between these variables requires additional empirical work that is beyond the scope of this paper.

to a value-at-risk constraint, whereby the likelihood that she makes negative profits cannot exceed some small $\alpha_t < 1$.[5,6] The representative financier thus faces the following problem at time $t \in \{0, 1\}$:

$$\begin{aligned} \max_{Q_t} \quad & \mathbb{E}_t[V_{t+1}] \\ \text{s.t.} \quad & \mathbb{P}_t(V_{t+1} \leq -\epsilon) \leq \alpha_t, \end{aligned} \tag{2}$$

where ϵ is some positive number arbitrarily close to zero.[7]

The presence of the value-at-risk constraint effectively limits the "risk-bearing capacity" of the financiers. When α_t is close to one, the representative financier is essentially unconstrained and can take arbitrarily large currency positions. However, if α_t is small, the constraint in (2) is tightened whenever the financier faces higher risk (e.g., due to an increase in the anticipated volatility of future exchange rates or interest rates). In this sense, the value-at-risk constraint induces a downward-sloping demand curve for risk-taking by the financiers.[8]

The competitive equilibrium of the economy described above is defined in a straightforward manner. It consists of the tuple $(e_0, e_1, e_2, Q_0, Q_1)$ of exchange rates and currency positions such that (i) the representative financier chooses Q_t so as to maximize her expected profit, taking the exchange rates as given, and (ii) the net demand for dollars is equal to zero in all periods:

$$de_0 - f_0 - Q_0 = 0 \tag{3}$$

$$de_1 - f_1 + R_0 Q_0 - Q_1 = 0 \tag{4}$$

$$de_2 - f_2 + R_1 Q_1 = 0, \tag{5}$$

where recall that, whenever $\sigma_R > 0$, the realization of R_1 becomes known at $t = 1$.

B. Monetary Policy Uncertainty

We start our analysis by characterizing how uncertainty about the future stance of monetary policy in the United States impacts the foreign currency's

[5] Formally, in proving our main results, we consider the case in which $\alpha_t \to 0$.

[6] Adrian and Shin (2014) show that value-at-risk constraints similar to that in our model can emerge as a result of a standard contracting framework with risk-shifting moral hazard.

[7] The assumption that ϵ is arbitrarily close (but not exactly equal) to zero is made for technical reasons and has no bearing on our results. In fact, we present our main results assuming that $\epsilon \to 0$.

[8] Gabaix and Maggiori (2015) consider an alternative specification of the model with a different constraint: the financiers are subject to a limited commitment friction that intensifies with the complexity of their balance sheets. Since both our value-at-risk constraint and the limited commitment constraint of Gabaix and Maggiori (2015) induce downward-sloping demand for risk-taking by the financiers, they have similar implications for exchange rates and currency excess returns.

(log) *excess return*, defined as $\phi = \phi_1 + \phi_2$, where

$$\phi_{t+1} = \log(R^*) - \log(R_t) + \log(e_{t+1}) - \log(e_t)$$

captures the foreign currency's excess return between periods t and $t+1$. Note that $\mathbb{E}_t[\phi_{t+1}] = 0$ is equivalent to the satisfaction of UIP between periods t and $t+1$. Since monetary policy uncertainty is resolved at $t = 1$, we can naturally interpret ϕ_1 and ϕ_2 as, respectively, the foreign currency's pre- and postannouncement excess returns. We have the following result.

PROPOSITION 1: *An increase in monetary policy uncertainty in the United States increases the foreign currency's expected excess return, that is,* $\partial\mathbb{E}_0[\phi]/\partial\sigma_R > 0$.

This proposition thus establishes that the foreign currency's excess return is higher on FOMC announcement days compared to days with no scheduled announcements. The intuition underlying this result is that, on announcement days, financiers are uncertain about the interest rate at which they will have to refinance their position, exposing them to a risk that is above and beyond the usual fundamental risk they face on nonannouncement days when $\sigma_R = 0$. Given their downward-sloping demand for risk-taking induced by the value-at-risk constraint, the financiers are willing to bear this extra risk only if they are compensated accordingly with a higher return. Put differently, the higher σ_R faced by financiers on announcement days tightens their value-at-risk constraint in (2), thus limiting their ability to short the dollar. Consequently, for currency markets to clear, the foreign currency has to depreciate at $t = 0$, followed by an expected appreciation at $t = 2$, thus increasing the excess return.

Our next result determines the relationship between the foreign currency's excess return and the interest rate differential between the two countries.

PROPOSITION 2: *The foreign currency's expected excess return increases in the foreign country's interest rate, that is,* $\partial\mathbb{E}_0[\phi]/\partial R^* > 0$. *Furthermore, the increase in excess return in response to higher monetary policy uncertainty is larger for currencies with higher interest rates, that is,* $\partial^2\mathbb{E}_0[\phi]/\partial R^*\partial\sigma_R > 0$.

The first part of the above result establishes that a higher interest rate differential between the two countries leads to a larger (expected) excess return on the foreign currency position. This is due to the fact that a higher interest rate differential between the two countries makes shorting the dollar more attractive for financiers, inducing them to take larger positions in equilibrium. This increase in position size results in an equilibrium exchange rate adjustment. However, due to financiers' limited risk-bearing capacity, the adjustment in exchange rates does not offset the increase in interest rate differential one-for-one, thus resulting in a higher excess return.

More importantly, however, the second part of Proposition 2 establishes that the impact of monetary policy uncertainty on excess returns (characterized in Proposition 1) is not the same for all currencies. Rather, returns that are earned as compensation for higher monetary policy uncertainty are larger for currencies with higher interest rates. The model thus predicts not only that the foreign currency earns higher excess returns on FOMC announcement days relative to nonannouncement days, but also that the difference between announcement- and nonannouncement-day returns increases with the country's interest rate differential vis-à-vis the United States.

C. Monetary Policy Shock

Our focus thus far has been on the impact of monetary policy uncertainty on excess returns. Indeed, the fact that this uncertainty is resolved at $t = 1$ means that the effects characterized in our previous results work through financiers' $t = 0$ expectations about future interest rates. As our next result, we show that, in addition to these expectations-driven effects, the actual realization of the monetary policy shock also affects the foreign currency's excess return. We capture this so-called "postannouncement effect" by characterizing the relationship between the realization of R_1 and the foreign currency's excess return between $t = 1$ and $t = 2$.

PROPOSITION 3: *An interest rate reduction by the Fed increases the foreign currency's expected postannouncement excess return, that is,* $\partial\mathbb{E}_1[\phi_2]/\partial R_1 < 0$. *Furthermore,* $\partial^2\mathbb{E}_1[\phi_2]/\partial R_1 \partial\sigma_R < 0$.

Thus, not only does the foreign currency exhibit higher excess returns on announcement days relative to nonannouncement days, but also its announcement-day return is higher if, ex post, the Fed adopts a policy of monetary easing. The juxtaposition of Propositions 1 and 3 also illustrates that the composition of announcement-day returns is driven by two related but distinct factors. First, the mere possibility of a change in interest rates in the United States results in higher monetary policy uncertainty and hence higher excess returns. Second, given that the policy announcement may result in an actual change in interest rates, the foreign currency's postannouncement return also adjusts in response to the adopted policy.

II. Data

We work with tick-by-tick high-frequency data that run from January 1, 1994, to December 31, 2013. There are eight scheduled FOMC meetings in one year. This leaves us with 160 FOMC announcement days and 4,512 trading days with no scheduled FOMC announcements. We exclude from our sample the 10 days during which the FOMC made a surprise announcement following an unscheduled meeting.

High-Frequency Currency Data: The high-frequency spot exchange rate data for Australia, Canada, Euro, Japan, New Zealand, Norway, Sweden, Switzerland, and the United Kingdom, all vis-à-vis the U.S. dollar, come from Olsen & Associates.[9] We focus on these so-called "G10" currencies as they are the most heavily traded (Bank for International Settlements (2015)). The raw

[9] We use the Deutsche mark instead of the euro prior to the latter's introduction in January 1999.

data consist of all interbank bid and ask indicative quotes for the exchange rates to the nearest even second. After filtering the data for outliers, the log price at each five-minute tick is obtained by linearly interpolating from the average of the log bid and log ask quotes for the two closest ticks.[10] We then calculate daily currency returns by sampling the data at 4 pm Eastern Time (ET).

Spot and Forward Data: The log excess return of purchasing a foreign currency in the forward market and then selling it in the spot market after one month is given by $rx_{t+1} = fw_t - s_{t+1}$, where s_t and fw_t denote the spot and forward rates in logs, respectively. The excess return can also be stated as the log forward discount minus the change in the spot rate: $rx_{t+1} = fw_t - s_t - \Delta s_{t+1}$. Note that, since covered interest rate parity (CIP) holds at daily and lower frequencies, the forward discount is equal to the interest rate differential, that is, $fw_t - s_t \approx r_t^* - r_t$, where r^* and r, respectively, denote the foreign nominal risk-free rate and domestic nominal risk-free rate over the maturity of the contract.

To calculate currency excess returns, we combine our high-frequency spot data with daily data for spot exchange rates and one-month-forward rates (versus the U.S. dollar) obtained from BBI and WM/Reuters (via Datastream). More specifically, we use the change in exchange rate from the high-frequency data and combine it with an appropriately scaled forward discount that is extracted from the daily data assuming that the interest is earned linearly over the length of the contract.

Volatilities: To obtain measures for intraday realized volatility, we first calculate spot exchange rate changes sampled at five-minute intervals and obtain the realized variance over a rolling one-hour window as the respective sum of squared changes. We then calculate realized volatility by taking the square root of realized variance.

FOMC Announcements: For a high-frequency analysis, it is important to know exactly when FOMC decisions become known to market participants. Unlike other macroeconomic announcements that are released at very precise times, FOMC announcements are usually made around, but not precisely at, 215 pm ET. We follow Fleming and Piazzesi (2005) and collect precise announcement times from the Bloomberg newswire, although, with some abuse of terminology, we use the terms "215 pm" and "the announcement time" interchangeably.

Monetary Policy Indicator: To obtain an indicator for monetary policy shocks, we follow Gürkaynak, Sack, and Swanson (2005) and Nakamura and Steinsson (2016) and construct a composite measure of changes in Fed funds and Eurodollar futures with horizons up to one year over a 30-minute window around FOMC announcements. This composite measure, which we refer to as the "monetary policy indicator" or MPI, is the first principal component

[10] We follow the literature and take five-minute intervals as opposed to higher frequencies to mitigate the effect of spurious serial correlation stemming from microstructure noise.

of unanticipated changes in the following five interest rates: the federal funds rate immediately following the FOMC meeting, the expected federal funds rate immediately following the next FOMC meeting, and expected three-month Eurodollar interest rates at horizons of two, three, and four quarters.

Uncertainty Indices: As our benchmark index for market participants' uncertainty about monetary policy, we use the implied volatility index extracted from one-month options on 30-year Treasury futures (akin to the VIX), which we refer to as Treasury Implied Volatility or TIV (Choi, Mueller, and Vedolin (2016)). In our robustness analysis, we also proxy for policy uncertainty using the economic policy uncertainty index of Baker, Bloom, and Davis (2016).

Finally, we proxy for market participants' appetite for risk and intermediaries' risk-bearing capacity using the VIX index of implied volatility from S&P500 options (Pan and Singleton (2008), Adrian and Shin (2010), Miranda-Agrippino and Rey (2015)), as well as the average five-year CDS spread of Citibank, JPMorgan, Bank of America, and Goldman Sachs, which is available from Markit. These banks, which are the four largest U.S.-based banks trading in the foreign exchange market, hold around 34% of the market share.

III. Empirical Analysis

This section contains our main empirical results, where we document that returns to a trading strategy that is short the U.S. dollar and long other currencies are on average larger on FOMC announcement days compared to all other days. We also show that the difference between announcement- and nonannouncement-day returns (i) is larger for currencies with larger interest rate differentials vis-à-vis the United States, (ii) increases with various proxies for monetary policy uncertainty, and (iii) is larger when the Federal Reserve adopts an expansionary monetary policy.

A. Announcement- versus Nonannouncement-Day Returns

Individual Currencies: We begin our empirical investigation by documenting the returns of individual currencies on days with and without scheduled FOMC announcements. Table I presents summary statistics for daily excess returns of the nine currencies in our sample (in bps) vis-à-vis the U.S. dollar for the full sample (Panel A), days without FOMC announcements (Panel B), and days with scheduled announcements (Panel C). The returns are sampled at 4 pm ET, which corresponds to the closing time of the stock market in New York.[11]

Several noteworthy observations emerge. First, focusing on the full sample in Panel A indicates that, except for the New Zealand dollar, daily returns are on average not statistically different from zero. Summary statistics for

[11] Benchmark exchange rates available through Datastream are sampled at 4 pm London time. To cover the most active trading period prior to the announcement, we instead focus on 4 pm ET, which is when the market closes in New York. We verify that the Datastream data and our high-frequency data when sampled at 4 pm London time are virtually identical.

Table I

Summary Statistics for Individual Currency Returns

This table reports summary statistics for individual currency returns for the full sample (Panel A), nonannouncement days (Panel B), and FOMC announcement days (Panel C). "Δs" represents the return earned from the change in the foreign exchange rate and "SR" is the Sharpe ratio. All numbers are expressed in daily bps except for Sharpe ratios, which are annualized, taking into account the annual frequency of FOMC announcements (8/252). "diff" indicates the difference between announcement- and nonannouncement-day returns in bps, with the corresponding t-statistic for a test of the difference in means between announcement and nonannouncement days reported in parentheses. Returns are sampled from 4 pm to 4 pm ET and cover the period January 1, 1994, to December 31, 2013.

	AUD	CAD	CHF	EUR	GBP	JPY	NOK	NZD	SEK
Panel A: Full Sample ($n = 4{,}672$)									
Mean	1.715	0.978	0.221	0.299	0.610	−1.088	0.935	2.222	0.977
t-stat	(1.47)	(1.31)	(0.21)	(0.32)	(0.74)	(−1.05)	(0.86)	(1.92)	(0.87)
Δs	0.897	0.959	0.991	0.516	0.249	0.104	0.529	1.155	0.886
Skewness	−0.354	−0.054	−0.291	0.015	−0.524	0.528	−0.140	−0.354	−0.076
Kurtosis	12.311	8.164	9.934	4.706	8.265	9.097	6.137	6.720	5.790
SR	0.341	0.304	0.049	0.073	0.173	−0.243	0.199	0.445	0.203
Panel B: Nonannouncement Days ($n = 4{,}512$)									
Mean	1.163	0.421	−0.108	−0.050	0.155	−0.973	0.706	1.745	0.641
t-stat	(0.98)	(0.56)	(−0.10)	(−0.05)	(0.19)	(−0.92)	(0.64)	(1.49)	(0.56)
Δs	0.345	0.402	0.661	0.167	−0.206	0.217	0.299	0.679	0.551
Skewness	−0.439	−0.250	−0.422	−0.049	−0.595	0.524	−0.162	−0.435	−0.133
Kurtosis	12.479	6.977	9.821	4.507	8.324	9.234	6.169	6.597	5.578
SR	0.229	0.130	−0.024	−0.012	0.043	−0.214	0.148	0.346	0.131
Panel C: Announcement Days ($n = 160$)									
Mean	17.283	16.692	9.507	10.136	13.452	−4.325	7.365	15.666	10.431
t-stat	(2.43)	(3.31)	(1.38)	(1.86)	(2.79)	(−0.77)	(1.20)	(2.22)	(1.77)
Δs	16.451	16.672	10.309	10.376	13.082	−3.074	7.011	14.581	10.328
Skewness	1.183	2.435	1.537	1.451	0.898	0.660	0.408	1.139	1.671
Kurtosis	8.218	18.220	9.441	8.164	6.106	5.188	5.183	7.808	11.615
SR	0.544	0.740	0.307	0.416	0.623	−0.173	0.269	0.497	0.396
diff	16.120	16.271	9.615	10.186	13.297	−3.351	6.659	13.920	9.789
	(2.51)	(3.96)	(1.69)	(1.96)	(2.94)	(−0.59)	(1.11)	(2.19)	(1.64)

nonannouncement days, detailed in Panel B, exhibit a similar pattern: average returns are not statistically different from zero for any of the currencies. Panel C, however, indicates that announcement-day returns are not only statistically different from zero for most of the currencies, but also significantly larger than nonannouncement-day returns. For example, the average daily return of the Australian dollar (AUD) on announcement days is 17.28 bps compared to 1.16 bps on nonannouncement days, amounting to a statistically significant difference of 16.12 bps (with a t-statistic of 2.51). In fact, as the bottom row of Table I illustrates, except for the Japanese yen and the Norwegian krona, differences in announcement- and nonannouncement-day returns are significant for all

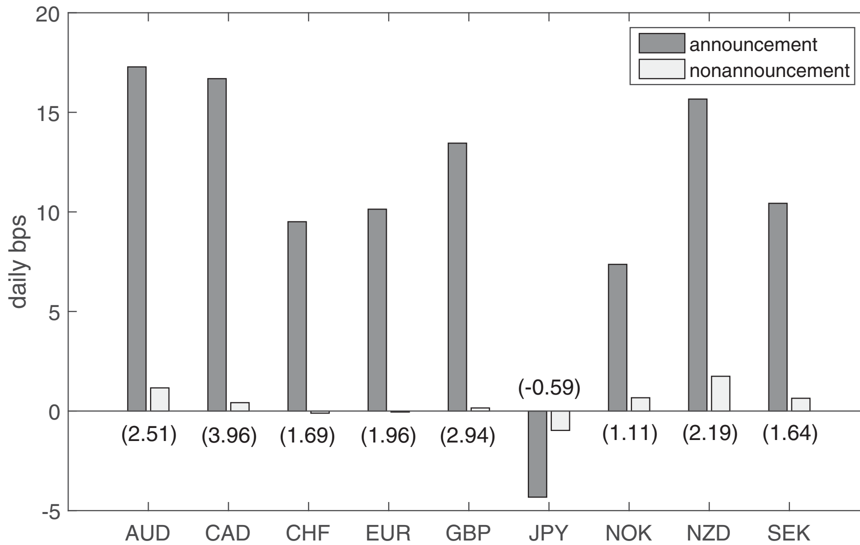

Figure 1. Currency returns on announcement and nonannouncement days. The figure plots average announcement- and nonannouncement-day returns for the currencies in our sample vis-à-vis the U.S. dollar. The numbers in parentheses report *t*-statistics for the tests of difference in mean returns between announcement and nonannouncement days. The data run from January 1, 1994, to December 31, 2013.

other currencies, an observation that is consistent with our model's prediction in Proposition 1. This pattern can also be seen in Figure 1, which plots the currencies' average daily returns on announcement and nonannouncement days.

Second, our results indicate that most of the currency excess returns earned on announcement days are due to changes in exchange rates as opposed to the interest rate differential. In particular, Δs in Panel C, which denotes the daily return that is earned as a consequence of changes in the foreign exchange, shows that almost the entire return on announcement days is attributable to the change in exchange rate.

Third, we note that the difference between returns earned on announcement and nonannouncement days is larger for currencies that have higher interest rate differentials vis-à-vis the United States. For example, the difference between announcement- and nonannouncement-day returns for the Australian and New Zealand dollars, two typical investment currencies, is 16.12 bps and 13.92 bps, respectively, both of which are statistically different from zero. In contrast, the difference between announcement- and nonannouncement-day returns for the Japanese yen, a typical funding currency, is statistically insignificant. This finding is in line with our model's prediction in Proposition 2, according to which currencies with larger interest rate differentials vis-à-vis the United States should exhibit larger excess returns on announcement days relative to nonannouncement days. We explore this issue in further detail below.

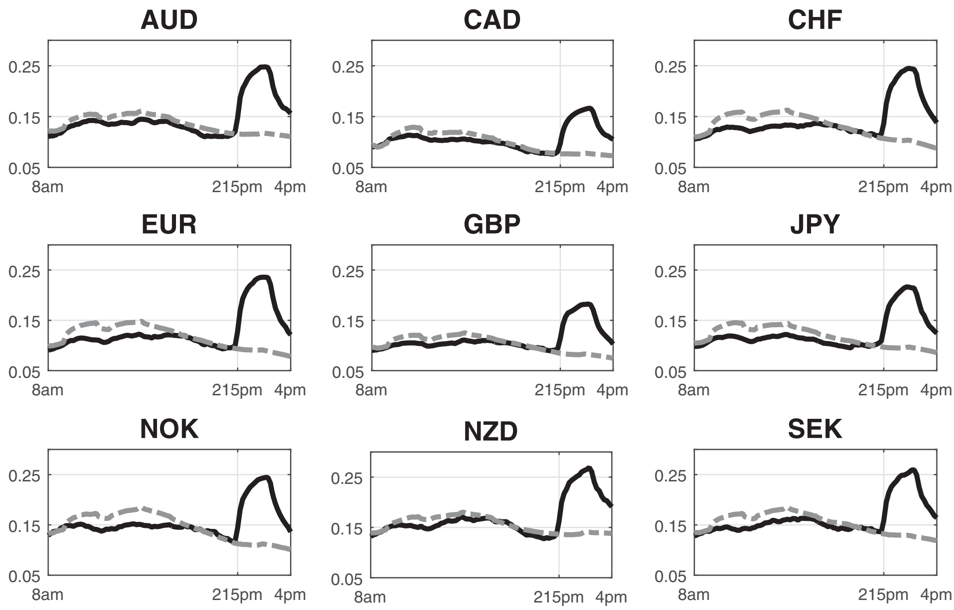

Figure 2. Foreign exchange realized volatility. This figure plots average realized exchange rate volatility on FOMC announcement days (solid curve) and all other days (dashed curve) from 8 am to 4 pm ET. Realized volatilities are calculated from data sampled at a five-minute frequency over a one-hour window and are annualized. The data run from January 1, 1994, to December 31, 2013.

We end this discussion by noting that, according to our model, currency excess returns are closely related to exchange rate volatility (via the tightness of financiers' risk constraint). To test for this relationship, we plot the daily movement of the average realized volatility of the currencies' exchange rates on announcement and nonannouncement days in Figure 2. As the figure indicates, throughout most of the day, realized volatility on announcement days is low and indistinguishable from realized volatility at corresponding times on nonannouncement days. However, realized volatility spikes considerably for all currencies around the time of the announcement. Indeed, performing an F-test on the data from a one-hour window straddling the time of the announcement indicates that, for all currencies, exchange rate volatility on announcement days is larger than on nonannouncement days (with p-values that are virtually equal to zero).

Currency Portfolios: In the remainder of this section, we focus our attention on currency portfolios, as most traders do not invest in single currencies. In particular, to diversify away idiosyncratic currency risks, many traders take a long position in a number of high interest rate currencies while shorting currencies with low interest rates (Pedersen (2015)).

Motivated by our earlier observation that currencies of countries with a positive interest rate differential vis-à-vis the United States exhibit larger returns on announcement days, we construct currency portfolios that are sorted on their forward discount, as is customary in the literature (see, e.g., Lustig and Verdelhan (2007) and Lustig, Roussanov, and Verdelhan (2011), among others). To this end, we allocate currencies into three portfolios based on their observed forward discounts $fw_t - s_t$ at the end of each month t, with pf1 and pf3 denoting the portfolios consisting of the three currencies with the lowest and highest interest rates, respectively.[12] We calculate individual currencies' daily log excess returns using the daily interest rate differentials and daily log exchange rate changes, assuming that the interest rate differential is earned linearly over the month. Portfolio returns are then calculated as the average of the currency excess returns in each portfolio as in Lustig, Roussanov, and Verdelhan (2011). Table II presents the resulting summary statistics, with dol denoting the portfolio that is short the U.S. dollar and long all other currencies.

Panel A of Table II presents summary statistics for average returns over our full sample. These results confirm the well-known empirical pattern that, when averaged over all days, low interest rate currencies earn lower average returns than high interest rate currencies: in our sample, the low interest rate portfolio, pf1, earns a daily return of −0.31 bps (with a t-statistic of −0.39), whereas the high interest rate portfolio, pf3, earns an average daily return of 2.18 bps (with a t-statistic of 2.31). The dol portfolio has a daily return of 0.84 bps, which is statistically insignificant (with a t-statistic of 1.14). Panel A also indicates that corresponding annualized Sharpe ratios are larger for high interest rate currencies: while pf1 generates an annualized Sharpe ratio of only −0.09, pf3 has a Sharpe ratio of 0.54.

Next, we compare the currency portfolios' returns on announcement and nonannouncement days, as documented in Panels B and C of Table II and depicted in Figure 3. The key observation is that, in line with the model's prediction in Propositions 1 and 2, the difference between announcement- and nonannouncement-day returns is positive and increasing in the interest rate differential. For instance, the average daily return on the low interest rate portfolio is 5.19 bps on announcement days compared to −0.51 bps on nonannouncement days. This 5.70 bps difference is positive but not statistically significant (with a t-statistic of 1.31). However, the average daily return of the high interest rate currency portfolio grows from 1.73 bps on nonannouncement days to 14.47 bps on announcement days, a 12.74 bps difference that is significantly different from zero (with a t-statistic of 2.45). We also note that, unlike the unconditional average taken over the entire sample (as presented in Panel A of Table II), the dol portfolio features a large and statistically significant return on announcement days (10.77 bps, with a t-statistic of 2.27), whereas the return on nonannouncement days is insignificant (with a t-statistic of 0.64). The difference of 10.30 bps between the announcement- and nonannouncement-day returns is highly statistically different from zero with a t-statistic of 2.55.

[12] Recall that, since CIP holds at daily and lower frequencies, the forward discount is equal to the interest rate differential.

Table II

Summary Statistics for Currency Portfolio Returns

This table reports summary statistics of currency portfolios for the full sample (Panel A), nonannouncement days (Panel B), and FOMC announcement days (Panel C). Portfolios are sorted according to their interest rate differentials, with pf1 (pf3) denoting the portfolio with the lowest (highest) interest rate differential vis-à-vis the United States. "dol" denotes the portfolio that is short the U.S. dollar and long all other currencies. "Δs" represents the return earned from the change in the foreign exchange rate and "SR" is the Sharpe ratio. All numbers are expressed in daily bps except for Sharpe ratios, which are annualized, taking into account the annual frequency of FOMC announcements (8/252). "diff" indicates the difference between announcement- and nonannouncement-day returns in bps, with the corresponding t-statistic for a test of the difference in means between announcement and nonannouncement days reported in parentheses. Returns are sampled from 4 pm to 4 pm ET and cover the period January 1, 1994 to December 31, 2013.

	pf1	pf2	pf3	dol
Panel A: Full Sample ($n = 4{,}672$)				
Mean	−0.307	0.638	2.183	0.838
t-stat	(−0.39)	(0.82)	(2.31)	(1.14)
Skewness	0.226	−0.028	−0.366	0.017
Kurtosis	6.059	6.980	8.695	5.874
SR	−0.090	0.189	0.537	0.265
Panel B: Nonannouncement Days ($n = 4{,}512$)				
Mean	−0.509	0.194	1.730	0.472
t-stat	(−0.64)	(0.24)	(1.81)	(0.64)
Skewness	0.156	−0.115	−0.461	−0.100
Kurtosis	5.941	6.711	8.629	5.471
SR	−0.148	0.057	0.421	0.148
Panel C: Announcement Days ($n = 160$)				
Mean	5.187	12.656	14.465	10.769
t-stat	(1.06)	(2.65)	(2.49)	(2.27)
Skewness	1.489	1.545	1.305	1.756
Kurtosis	7.235	10.174	8.384	9.621
SR	0.238	0.593	0.556	0.508
diff	5.696	12.462	12.735	10.298
	(1.31)	(2.90)	(2.45)	(2.55)

These observations illustrate that a sizable portion of currency portfolios' average yearly returns is earned on FOMC announcement days. For instance, the average yearly return on the high interest rate portfolio is $252 \times 2.183 = 550$ bps, of which 21% (or $8 \times 14.465 = 116$ bps) is earned on the eight FOMC announcement days. For the dol portfolio, we find that 41% of the entire annual return is earned on announcement days. Notably, this large increase in average returns on announcement days is not accompanied by an equally large increase in realized risk, as annualized Sharpe ratios are significantly larger

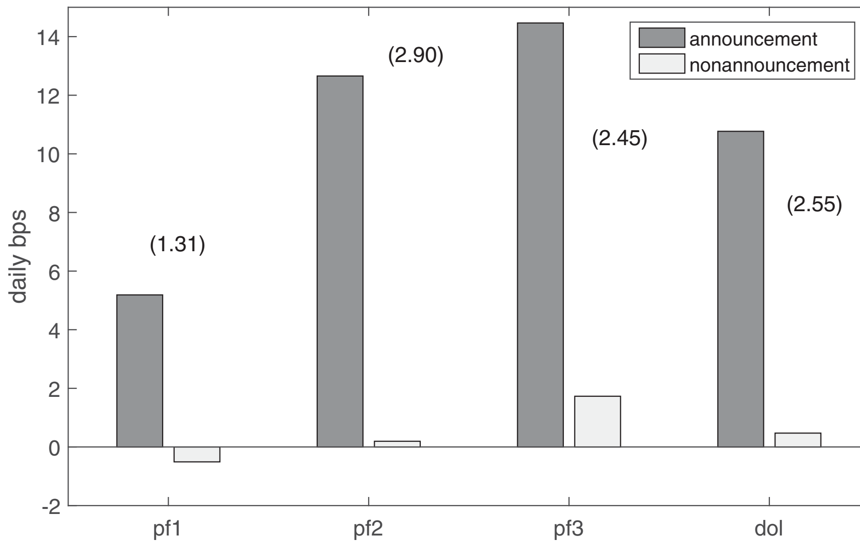

Figure 3. Currency portfolio returns on announcement and nonannouncement days. The figure plots average announcement- and nonannouncement-day returns for portfolios sorted according to interest rate differentials vis-à-vis the United States, with pf1 (pf3) denoting the portfolio with the lowest (highest) interest rate differential. dol denotes the portfolio that is short the U.S. dollar and long all other currencies. The numbers in parentheses report *t*-statistics for the tests of difference in mean returns between announcement and nonannouncement days. The data run from January 1, 1994, to December 31, 2013.

on announcement days.[13] We also note that, even though announcement-day Sharpe ratios are comparable to those of some of the established currency trading strategies, it is well known that carry trades feature negative skewness (Brunnermeier, Nagel, and Pedersen (2008), Jurek (2014), Daniel, Hodrick, and Lu (2016)). In contrast, the relatively high Sharpe ratios of pf3 and dol on announcement days are accompanied by returns that are positively skewed.

B. Time-Series Analysis

We continue our investigation of currency excess returns around FOMC announcements by taking a time-series perspective. This approach enables us to test our model's theoretical predictions in further detail and study the potential determinants of announcement-day returns more formally.

We start by documenting how monetary policy uncertainty and the realization of monetary policy shocks shape currency excess returns on announcement days. As our benchmark regression, we regress each currency portfolio's excess returns on a dummy variable that takes the value of one on announcement

[13] Annualized Sharpe ratios are obtained by adjusting daily values for the yearly frequency of FOMC announcements (8 out of 252 trading days). Thus, the adjustment factors for announcement- and nonannouncement-day Sharpe ratios are $\sqrt{8}$ and $\sqrt{244}$, respectively.

Table III

Currency Portfolio Returns Time-Series Regressions

This table reports results of time-series regressions of interest rate–sorted currency portfolios. The dependent variable is the portfolios' excess returns from 4 pm to 4 pm ET. "Announcement" is a dummy variable that is equal to one on days when the FOMC makes an announcement and zero otherwise. "TIV" is the standardized (that is, demeaned and scaled by the corresponding sample standard deviation) Treasury Implied Volatility index extracted from one-month options on 30-year Treasury futures. "MPI" is Nakamura and Steinsson's (2016) indicator of monetary policy shock. The data run from January 1, 1994, to December 31, 2013. Numbers in parentheses denote Newey and West (1987) t-statistics.

	pf1	pf2	pf3	dol
Panel A: Baseline Regression				
Constant	−0.502	0.212	1.747	0.486
	(−0.62)	(0.27)	(1.82)	(0.65)
Announcement	5.689	12.444	12.718	10.283
	(1.31)	(2.89)	(2.45)	(2.55)
Adj. R^2	0.02%	0.16%	0.11%	0.12%
Panel B: Monetary Policy Uncertainty				
Constant	−0.504	0.215	1.750	0.487
	(−0.63)	(0.27)	(1.83)	(0.65)
Announcement	6.818	13.669	14.662	11.716
	(1.56)	(3.16)	(2.82)	(2.90)
TIV	0.436	−0.718	−0.814	−0.365
	(0.54)	(−0.90)	(−0.85)	(−0.49)
TIV × Announcement	10.896	13.054	20.384	14.778
	(2.47)	(3.00)	(3.88)	(3.62)
Adj. R^2	0.12%	0.31%	0.39%	0.36%
Panel C: Monetary Policy Shock				
Constant	−0.502	0.212	1.747	0.486
	(−0.62)	(0.27)	(1.82)	(0.65)
Announcement	7.059	13.736	14.369	11.721
	(1.62)	(3.19)	(2.77)	(2.91)
MPI × Announcement	3.888	3.667	4.688	4.081
	(4.66)	(4.45)	(4.72)	(5.29)
Adj. R^2	0.46%	0.56%	0.56%	0.69%

days and zero otherwise:

$$rx_{t+1} = \alpha_0 + \alpha_1 \times Announcement_t + \epsilon_{t+1}. \tag{6}$$

In this regression, the intercept α_0 measures the corresponding portfolio's mean return on nonannouncement days, while α_1 measures the spread between mean returns earned on announcement and nonannouncement days.

The results, reported in Panel A of Table III, mirror those in Table II, with positive coefficients on the announcement dummy for all portfolios. Furthermore, except for the low interest rate portfolio, the spread between announcement- and nonannouncement-day returns is significant for all portfolios, with $\alpha_1 = 12.72$ (t-statistic of 2.45) for the high interest rate portfolio. The estimates for the intercept α_0 are not significant except for pf3, implying that there is little return to be earned on nonannouncement days. Similarly, for the dol portfolio, the coefficient on the announcement dummy ($\alpha_1 = 10.28$) is statistically significant whereas the intercept is not. These results thus confirm our model's main prediction that currency excess returns are higher on average on announcement days. Also recall that, according to our model, the difference between returns earned on announcement and nonannouncement days should increase with the currency portfolios' interest rate differential vis-à-vis the United States (Proposition 2). We find that the estimated coefficients do indeed increase from 5.69 for pf1 to 12.72 for pf3.

Next, we test our model's other prediction that larger currency excess returns on announcement days are in response to the presence of monetary policy uncertainty (Proposition 1). To check whether higher announcement-day returns are indeed associated with higher monetary policy uncertainty, we regress currency excess returns on the announcement dummy interacted with the (standardized) implied volatility index TIV, which serves as a proxy for monetary policy uncertainty:

$$rx_{t+1} = \alpha_0 + \alpha_1 \times Announcement_t + \alpha_2 \times TIV_t + \alpha_3 \times Announcement_t \times TIV_t + \epsilon_{t+1}. \tag{7}$$

In this regression, we are mainly interested in the coefficient α_3, which measures the additional return that one can earn on announcement days relative to nonannouncement days as TIV increases. The results are reported in Panel B of Table III. We find that all estimated coefficients on the interaction term are statistically significant at the 1% level and carry the expected positive sign, indicating that higher uncertainty is indeed associated with a larger spread between announcement- and nonannouncement-day excess returns. Interestingly, monetary policy uncertainty does not seem to matter for currency returns outside of announcement days as manifested by the insignificant estimates for α_2.

Finally, we test for the relationship between currency excess returns and the realization of the monetary policy shock at the announcement. Recall that, according to Proposition 3, the difference between returns on announcement and nonannouncement days should increase (decrease) if the Fed adopts a policy of monetary easing (tightening). To test for this prediction, we regress currency returns on the announcement dummy interacted with the monetary policy indicator of Nakamura and Steinsson (2016). This indicator, which we refer to as MPI, is obtained by extracting the principal component of changes in various interest rate futures, with a positive value corresponding to an expansionary change in policy. Our rationale for relying on such an indicator, as opposed to the change in the federal funds rate announced by the FOMC, is twofold. First, within our sample of 160 announcements, the federal funds rate was changed on only 52 occasions (corresponding to 30 and 22 rate hikes and reductions, respectively), thus leaving us with too small of a sample. In contrast, by relying on the MPI, we can identify 59 and 101 episodes of policy easing and tightening, respectively. Second, given its overnight nature, changes in the federal funds rate are incapable of capturing any longer term changes in (expected) interest rates as a result of the FOMC announcement. In contrast, such potential changes are better reflected in the MPI due to its longer horizon nature.

Panel C of Table III reports the results. Estimated coefficients are positive and highly statistically significant for all portfolios with t-statistics ranging between 4.45 and 5.29. These results thus indicate that, consistent with the predictions of Proposition 3, the adoption of an expansionary policy by the Fed increases the spread between announcement- and nonannouncement-day returns.

B.1. Pre- and Postannouncement Returns

One of the key predictions of our model is that currency excess returns consist of pre- and postannouncement components. To test this prediction and explore the intraday patterns of returns, we decompose daily returns by sampling the data at 215 pm and 4 pm and calculate currency returns over two nonoverlapping time windows: (i) from 4 pm on any given day to 215 pm the following day and (ii) from 215 pm to 4 pm on the same day. We then separately regress the returns earned over each time window on an announcement dummy in a regression akin to (6). With some abuse of terminology, we refer to the 4 pm to 215 pm and 215 pm to 4 pm time windows as the pre- and postannouncement windows, respectively.

The results are summarized in Table IV, where Panels B and C report the corresponding numbers for pre- and postannouncement windows, respectively. As a reference, we also reproduce in Panel A the results of our baseline regression for the entire day (from Table III). The positive and significant estimates for the announcement dummy indicate that, except for pf1's returns during the preannouncement window, the pre- and postannouncement components of all portfolios are larger on announcement days compared to the corresponding windows on nonannouncement days (at the 10% level). For instance, the estimated coefficients for the dol portfolio over the preannouncement window indicate 7.89 bps higher returns on announcement days compared to the same time window on all other days (with an associated t-statistic of 2.02). Similarly, the returns of the dol portfolio during the postannouncement window of 215 pm to 4 pm are 2.39 bps (t-statistic of 2.32) higher on announcement days than on nonannouncement days.

Comparing the three panels of Table IV side-by-side also provides a clear decomposition of the portfolios' daily returns earned over the two time windows. For instance, focusing on pf3, the table illustrates that, when compared to nonannouncement days, of the 12.72 bps additional returns earned on announcement days, 9.48 bps are earned over the preannouncement window, with the remaining 3.24 bps earned over the postannouncement window.

Table IV

Pre- and Postannouncement Returns

This table reports results of time-series regressions of interest rate–sorted currency portfolios for different time windows. The dependent variable is the portfolios' excess returns from 4 pm to 4 pm (Panel A), from 4 pm to 215 pm (Panel B), and from 215 pm to 4 pm (Panel C). "Announcement" is a dummy variable that is equal to one on days when the FOMC makes an announcement and zero otherwise. The data run from January 1, 1994, to December 31, 2013. Numbers in parentheses denote Newey and West (1987) t-statistics.

	pf1	pf2	pf3	dol
Panel A: Entire Day (4 pm to 4 pm)				
Constant	−0.502	0.212	1.747	0.486
	(−0.62)	(0.27)	(1.82)	(0.65)
Announcement	5.689	12.444	12.718	10.283
	(1.31)	(2.89)	(2.45)	(2.55)
Adj. R^2	0.02%	0.16%	0.11%	0.12%
Panel B: Preannouncement Window (4 pm to 215 pm)				
Constant	−0.613	−0.457	1.360	0.135
	(−0.77)	(−0.59)	(1.48)	(0.19)
Announcement	3.806	10.415	9.484	7.894
	(0.89)	(2.49)	(1.91)	(2.02)
Adj. R^2	0.00%	0.11%	0.06%	0.07%
Panel C: Postannouncement Window (215 pm to 4 pm)				
Constant	0.111	0.673	0.391	0.394
	(0.61)	(3.43)	(1.40)	(2.07)
Announcement	1.881	2.028	3.237	2.387
	(1.90)	(1.92)	(2.15)	(2.32)
Adj. R^2	0.06%	0.06%	0.08%	0.09%

B.2. Preannouncement Returns and Monetary Policy Uncertainty

Recall from Section I that, according to our model, the excess returns earned prior to the announcement are in response to the presence of higher monetary policy uncertainty on announcement days. We test for this prediction by rerunning regression (7) while replacing returns earned over the entire day as the left-hand-side variable with the returns earned over the preannouncement window (4 pm to 215 pm). The results are presented in Table V. Similar to the results for the entire-day returns reported in Panel B of Table III, the estimated coefficient on the announcement dummy interacted with TIV (which serves as our proxy for monetary policy uncertainty) is positive and significant for all portfolios (with t-statistics ranging from 2.24 to 3.45). Furthermore, as reflected by the insignificant estimates for the coefficient on TIV, we find that monetary policy uncertainty does not matter for currency returns on nonannouncement days.

Table V

Monetary Policy Uncertainty and Preannouncement Returns

This table reports results of time-series regressions of interest rate-sorted currency portfolios for the preannouncement window. The dependent variable is the portfolios' excess returns from 4 pm to 215 pm. "Announcement" is a dummy variable that is equal to one on days when the FOMC makes an announcement and zero otherwise. "TIV" is the standardized Treasury Implied Volatility index extracted from one-month options on 30-year Treasury futures. The data run from January 1, 1994, to December 31, 2013. Numbers in parentheses denote Newey and West (1987) t-statistics.

	pf1	pf2	pf3	dol
Constant	−0.614	−0.453	1.363	0.136
	(−0.77)	(−0.59)	(1.49)	(0.19)
Announcement	4.822	11.397	11.114	9.106
	(1.12)	(2.71)	(2.23)	(2.32)
TIV	0.473	−1.133	−0.914	−0.503
	(0.60)	(−1.46)	(−1.00)	(−0.70)
TIV × Announcement	9.723	11.048	17.337	12.698
	(2.24)	(2.60)	(3.45)	(3.21)
Adj. R^2	0.08%	0.23%	0.27%	0.24%

B.3. Postannouncement Returns and the Monetary Policy Shock

Besides the decomposition of returns into their pre- and postannouncement components, our model also predicts that returns over the postannouncement window are tightly linked to the realization of the monetary policy shock at the announcement. In particular, recall from Proposition 3 that the adoption of a policy of monetary easing should result in a further increase in excess returns after the announcement. We explore the determinants of postannouncement returns by formally testing this relationship in our sample.

As a first exercise, we restrict our attention to announcement days only and calculate average returns during the postannouncement window conditional on whether the monetary shock was expansionary or contractionary. In particular, we divide announcement days into two separate categories conditional on the sign of our monetary policy indicator, with a positive MPI corresponding to a policy of monetary easing. Figure 4 presents the results. As the figure indicates, returns over the postannouncement window are positive and significant for all portfolios whenever the Fed adopts a policy of monetary easing (returns range from 18.33 bps with a t-statistic of 3.90 for pf1 to 24.32 bps with a t-statistic of 4.30 for pf3). We also find that returns are negative and significant during tightening periods, with returns ranging from −6.55 bps to −8.46 bps. Thus, in line with our theoretical model, we can conclude that an expansionary policy results in positive returns postannouncement, whereas a contractionary policy leads to negative average returns.

In a second exercise, we study how the realization of the monetary policy shock impacts the difference between announcement- and nonannouncement-day returns over the postannouncement window. To this end, we regress the currency portfolios' returns earned over the postannouncement window on the

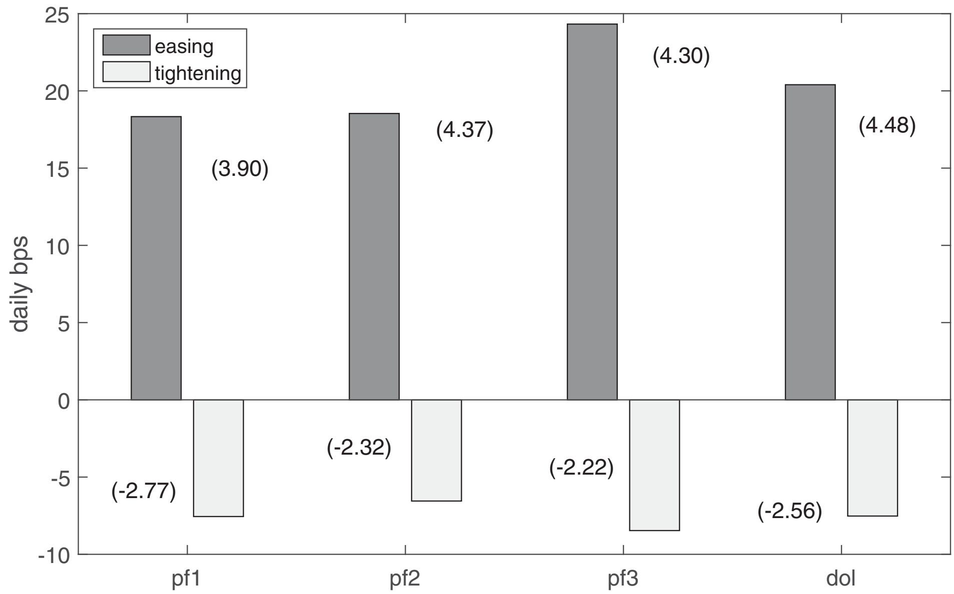

Figure 4. Postannouncement returns following monetary easing and tightening. This figure plots average announcement-day returns over the postannouncement window (215 pm to 4 pm) conditional on the sign of the realized monetary policy shock at the announcement. Monetary easing and tightening are defined using Nakamura and Steinsson's (2015) indicator of monetary policy shock. The numbers in parentheses report *t*-statistics for the test of zero mean. The data run from January 1, 1994, to December 31, 2013.

announcement dummy interacted with the MPI, akin to the results presented in Panel C of Table III for the entire day. The results are reported in Table VI, where all estimated coefficients are positive and highly statistically different from zero. Thus, in line with our model's prediction, we find that the difference between announcement- and nonannouncement-day returns over the postannouncement window is higher the more expansionary is the adopted policy.[14]

C. Trading Strategies

Our results thus far illustrate that a simple trading strategy that is short the U.S. dollar and long other currencies (i) exhibits high excess returns on FOMC announcement days, (ii) earns higher returns if the interest rate differential is larger, and (iii) results in larger returns over the postannouncement window if the Federal Reserve adopts a policy of monetary easing.

Taken together, these observations imply that the simple trading strategies that we have focused on thus far can be improved along two dimensions. First, the fact that the stance of monetary policy at the announcement is tightly

[14] We perform the same set of exercises for individual currencies and find a similar pattern. Details are provided in the Internet Appendix.

Table VI

Monetary Policy Shock and Postannouncement Returns

This table reports results of time-series regressions of interest rate–sorted currency portfolios for the postannouncement window. The dependent variable is the portfolios' excess returns from 215 pm to 4 pm. "Announcement" is a dummy variable that is equal to one on days when the FOMC makes an announcement and zero otherwise. "MPI" is Nakamura and Steinsson's (2016) indicator of monetary policy shock. The data run from January 1, 1994, to December 31, 2013. Numbers in parentheses denote Newey and West (1987) t-statistics.

	pf1	pf2	pf3	dol
Constant	0.111	0.673	0.391	0.394
	(0.62)	(3.48)	(1.42)	(2.11)
Announcement	2.792	2.848	4.186	3.280
	(2.87)	(2.72)	(2.80)	(3.24)
MPI $\times$ Announcement	2.586	2.327	2.695	2.536
	(13.88)	(11.61)	(9.42)	(13.07)
Adj. R^2	4.00%	2.84%	1.92%	3.60%

linked to postannouncement returns means that a trading strategy that responds to the content of the announcement should exhibit higher returns compared to simpler strategies that do not. One such strategy, which we label S1, shorts the U.S. dollar and goes long all other currencies at 4 pm the day before the announcement and keeps the portfolio until 4 pm on the day of the announcement if the Federal Reserve adopts an expansionary policy. If, however, the Federal Reserve tightens the policy, the strategy reverses the trade right after the announcement by going long the U.S. dollar and shorting the basket of all other currencies.

Second, the observation that the interest rate differential plays a key role in determining announcement-day returns means that S1 can be further improved if we only apply the strategy to currencies of countries that have a positive interest rate differential vis-à-vis the United States, a strategy that we label S2.

Summary statistics for announcement-day returns of these trading strategies are presented in Table VII. We note that average returns are indeed larger than those reported in Table II: S1 and S2 generate average returns of 19.49 bps and 22.54 bps, respectively, compared to 14.47 bps and 10.77 bps for the pf3 and dol portfolios. Furthermore, these returns not only are highly statistically significant (as indicated by the corresponding t-statistics), but also exhibit very large Sharpe ratios, increasing from approximately 0.5 for pf3 and dol to over 0.9 for either of the improved currency strategies. These Sharpe ratios are of similar orders of magnitude as the dollar carry strategy of Lustig, Roussanov, and Verdelhan (2014) for an extended set of currencies, which exploits the time variation in interest rate differentials vis-à-vis the United States. However, in addition to the high returns and large Sharpe ratios obtained on announcement days, the improved strategies S1 and S2 also exhibit positive skewness, a feature that is in contrast to the negative skewness observed

Table VII

Summary Statistics for Currency Strategies

This table reports summary statistics for currency returns on announcement days for two currency strategies. Strategy "S1" shorts the U.S. dollar and goes long the other currencies at 4 pm the day before the announcement. It then continues the trading strategy postannouncement in the case of monetary easing, whereas it goes long in the U.S. dollar and short in the other currencies after the announcement in the case of monetary tightening. "S2" is the same strategy but only uses currencies that exhibit a positive interest rate differential vis-à-vis the United States. The sample covers January 1, 1994, to December 31, 2013. All numbers are expressed in daily returns (in bps) except for Sharpe ratios, which are annualized.

	S1	S2
Mean	19.485	22.538
t-stat	(4.11)	(4.17)
Skewness	1.759	1.612
Kurtosis	8.762	8.293
SR	0.920	0.933

for most of the well-known currency trading strategies (Daniel, Hodrick, and Lu (2016)).

Finally, comparing announcement-day returns in the foreign exchange market to their counterparts in the equity market suggests that, even though the former are smaller on average, the two are quite similar in terms of Sharpe ratios. In particular, we calculate preannouncement returns in the equity market as in Lucca and Moench (2015) for an extended sample ending in 2013 and find an average daily return of approximately 40 bps with an associated annualized Sharpe ratio of 1.04. While announcement returns in the foreign exchange market are smaller—the average return for S2 is 22 bps—the currency strategies exhibit Sharpe ratios that are comparable to those in the equity market.

D. Announcements by Other Central Banks

One natural question that arises is whether announcements by other central banks have implications for currency returns that are similar to the patterns we document for FOMC announcements. To answer this question, we collect announcement dates for the central banks of Australia, England, Japan, New Zealand, and Switzerland either from Bloomberg (if available) or from the web pages of the corresponding central banks.[15] Next we re-base all exchange rates into the local currency of interest, assuming there are no violations of triangular arbitrage. We then build three portfolios based on interest rate differentials vis-à-vis the respective country and rerun the same exercise as we did for FOMC announcements. We do not find any significant effects

[15] The remaining countries have either a very short history or a small number of scheduled announcements, making any meaningful statistical analysis impossible. For example, Bank of Canada only started a fixed announcement schedule from 2001 onwards and Norges Bank met only once per year until 2007.

for other central bank announcements except for the BoJ.[16] In what follows, we first discuss Japan's monetary policy in more detail and then present the results.

The BoJ Policy Board meets once or twice a month for two days to discuss economic developments inside and outside of the country. During these Monetary Policy Meetings, the Policy Board produces a guideline for money market operations in intermeeting periods. This guideline is written in terms of a target for the uncollateralized overnight call rate (the policy interest rate that corresponds to the federal funds rate in the United States), which is the base rate that is charged when banks that are part of the system provide one another loans with a short maturity, usually a maturity of one day (overnight). The uncollateralized call rate was lowered to virtually zero in February/March 1999, and, with the exception of a brief interest rate increase in the fall of 2000, the rate has remained at the zero lower bound since.

The monetary policy decisions are announced right after the meeting, with the minutes released about a month later. It is important to note that, in addition to setting the interest rate, the BoJ's monetary policy announcements entail setting the target (reserves) of commercial banks at the BoJ in excess of required reserves as well as the size of outright purchases of long-term government bonds, private equity, and debt, such as asset-backed securities. These announcements also include the BoJ's collective outlook on the economy and guidance about future monetary policy decisions.[17]

Monetary Policy Meeting dates are available from the BoJ's web page since 1998, when the BoJ gained independence from the government in its policy-making decisions and member appointments. To test for announcement-day effects, we re-base all exchange rates vis-à-vis the Japanese yen and sort the currencies into three different portfolios based on their interest rate differentials. The results are presented in Table VIII.

The findings are strikingly similar to those for the Federal Reserve. On days with a BoJ announcement, the average daily return on the low interest rate portfolio is 12.47 bps, compared to −0.04 bps on nonannouncement days. This difference of 12.51 bps is significantly different from zero, with a t-statistic of 2.20. For the high interest rate currency portfolio, the average announcement-day return is 17.59 bps compared to 2.82 bps on nonannouncement days; the 14.77 bps difference is significantly different from zero (t-statistic of 2.27). In a pattern mirroring that of FOMC announcements, the large increases in average returns on BoJ announcement days is not accompanied by an equally large increase in realized risk, as annualized Sharpe ratios are large and economically significant, ranging from 1.07 for pf1 to 1.32 for pf3.

These observations indicate that, similar to the results for the United States, a sizable portion of the portfolios' average yearly returns is earned

[16] In contrast, Brusa, Savor, and Wilson (2016) document that there are no effects on global stock market indices from announcements by central banks other than the Fed, arguing that the Fed exerts a unique impact on global equity prices.

[17] See Kuttner (2014) for an excellent overview of Japan's monetary policy.

Table VIII

Announcements by the Bank of Japan

This table reports summary statistics for currency portfolios for the full sample (Panel A), days without an announcement by the BoJ (Panel B), and BoJ announcement days (Panel C). Announcement days are when the BoJ releases its interest rate decisions. Portfolios are sorted according to their interest rate differentials, with pf1 (pf3) denoting the portfolio with the lowest (highest) interest rate differential vis-à-vis Japan. "jpy" denotes the portfolio that is short the Japanese yen and long all other currencies. "SR" is the Sharpe ratio. All numbers are expressed in daily bps except for Sharpe ratios, which are annualized, taking into account the annual frequency of BoJ announcements (15/252). "diff" indicates the difference between announcement- and nonannouncement-day returns in bps, with the corresponding t-statistic for a test of the difference in means between announcement and nonannouncement days reported in parentheses.

	pf1	pf2	pf3	jpy
Panel A: Full Sample ($n = 3{,}997$)				
Mean	0.410	1.657	3.340	1.802
t-stat	(0.39)	(1.47)	(2.58)	(1.64)
Skewness	−0.498	−0.663	−0.593	−0.641
Kurtosis	8.246	10.138	11.572	10.438
SR	0.088	0.330	0.579	0.369
Panel B: Nonannouncement Days ($n = 3{,}765$)				
Mean	−0.039	1.191	2.823	1.325
t-stat	(−0.05)	(1.32)	(2.71)	(1.50)
Skewness	−0.512	−0.684	−0.619	−0.663
Kurtosis	8.427	10.361	11.737	10.641
SR	−0.008	0.230	0.474	0.263
Panel C: Announcement Days ($n = 232$)				
Mean	12.467	14.040	17.592	14.699
t-stat	(2.23)	(2.37)	(2.76)	(2.60)
Skewness	−0.159	−0.157	0.265	−0.062
kurtosis	3.849	4.508	5.860	4.895
SR	1.067	1.133	1.320	1.242
diff	12.506	12.849	14.769	13.375
	(2.20)	(2.13)	(2.27)	(2.32)

on the BoJ announcement days. For instance, the average yearly return on pf3 is $3.34 \times 252 = 842$ bps, of which 31% (or $15 \times 17.59 = 264$ bps) is earned on the 15 announcement days. Similarly, for the portfolio that is long all currencies and short the Japanese yen (reported in the last column in Table VIII), announcement-day returns account for 49% of the annualized premium ($14.70\,\text{bps} \times 15/1.80\,\text{bps} \times 252$).

We end this discussion by noting that the similarity between the results for the BoJ and the FOMC should not be considered surprising, as the Japanese yen serves as one of the most prominent funding currencies. In fact, this similarity is in line with our model's prediction, according to which a higher interest rate differential between the funding and investment currencies leads to a larger difference between returns on announcement and nonannouncement days.

E. Robustness

We conclude this section by running several robustness checks. First, we rerun our analysis by using alternative proxies for market participants' uncertainty about monetary policy. Second, we check the impact of transaction costs on returns. Third, we repeat the analysis for truncated data to ensure that our results are not driven by outliers in the sample. Fourth, in a pair of bootstrap exercises, we compute small-sample standard errors (to overcome concerns about sample size) and sample randomly from the distribution of returns on nonannouncement days (to test whether one can generate returns similar in size to those observed on announcement days). Finally, we check whether other macroeconomic announcements result in similarly large returns as those documented for FOMC announcements.

E.1. Alternative Measures of Uncertainty

In our first set of robustness checks, we verify that the positive relationship between monetary policy uncertainty and currency excess returns on announcement days that we document above is not driven by our choice of uncertainty measure.

In Table IX, we summarize the estimated coefficients from rerunning regression (7) using an alternative measure of policy uncertainty: Baker, Bloom, and Davis's (2016) economic policy uncertainty index (EPU). As the table suggests, similar to our results in Panel B of Table III, the estimated coefficients on the interaction term (i.e., α_3 in equation (7)) are positive and mostly significant.

To test our model's prediction that excess returns increase with exchange rate volatility, we regress portfolio excess returns on the announcement dummy interacted with the realized exchange rate volatility sampled from the high-frequency data at 215 pm. As expected, the estimated coefficients, which are also presented in Table IX, are all positive and highly significant.

Finally, we regress each portfolio's excess returns on the announcement dummy interacted with the VIX index of implied volatility of S&P500 options, which serves as a proxy for market participants' aversion to risk (Pan and Singleton (2008), Adrian and Shin (2010)). As expected, the corresponding coefficients are all positive and significant. We also replicate this exercise after replacing VIX with the average CDS spreads of the four largest U.S.-based banks active in the foreign exchange market. The positive and significant coefficients on the interaction term documented in Table IX indicate that excess returns increase when spreads widen.

E.2. Transaction Costs

To account for possible transaction costs, we construct portfolios' net returns on announcement days by adjusting for bid-ask spreads. The net excess return

Table IX

Alternative Measures of Uncertainty

This table reports results of time-series regressions of interest rate–sorted currency portfolios on various explanatory variables akin to equation (7). "pf1" and "pf3" denote the portfolios with the lowest and highest interest rate differential vis-à-vis the United States, respectively. "dol" denotes the portfolio that is short the U.S. dollar and long all other currencies. The dependent variable is portfolios' excess returns from 4 pm to 4 pm ET. "Announcement" is a dummy variable that is equal to one on days when the FOMC makes an announcement and zero otherwise. "EPU" is the economic policy uncertainty index of Baker, Bloom, and Davis (2016), "RV" is realized exchange rate volatility measured over a two-hour window around the time of an FOMC announcement, "VIX" is S&P500 implied volatility, and "CDS" is the average five-year CDS spread of Citibank, JPMorgan, Bank of America, and Goldman Sachs. EPU, RV, VIX, and CDS are demeaned and scaled by their respective sample standard deviations. The data run from January 1, 1994, to December 31, 2013 for all regressions except for the CDS regressions, which run from April 1, 2001, to December 31, 2010. Newey and West (1987) t-statistics are in parentheses.

	RV				CDS			
	pf1	pf2	pf3	dol	pf1	pf2	pf3	dol
Constant	−0.712	−0.047	1.405	0.215	0.579	0.936	2.870	1.462
	(−0.86)	(−0.06)	(1.34)	(0.27)	(0.60)	(0.86)	(2.08)	(1.43)
Announcement	6.849	13.614	14.330	11.598	10.075	18.339	19.059	15.824
	(1.54)	(2.95)	(2.53)	(2.69)	(1.93)	(3.12)	(2.56)	(2.87)
Uncertainty Index	−0.311	−3.306	−3.999	−2.538	−1.578	−2.096	−1.905	−1.860
	(−0.38)	(−3.86)	(−3.81)	(−3.18)	(−1.63)	(−1.92)	(−1.38)	(−1.82)
Uncertainty Index ×	18.161	23.713	32.490	24.788	8.206	11.943	17.680	12.610
Announcement	(4.17)	(5.25)	(5.87)	(5.88)	(1.54)	(1.99)	(2.33)	(2.25)
Adj. R^2	0.41%	1.00%	1.08%	1.03%	0.17%	0.44%	0.33%	0.41%
	VIX				EPU			
	pf1	pf2	pf3	dol	pf1	pf2	pf3	dol
Constant	−0.506	0.211	1.731	0.479	−0.506	0.203	1.737	0.478
	(−0.63)	(0.27)	(1.81)	(0.64)	(−0.63)	(0.26)	(1.81)	(0.64)
Announcement	5.931	12.677	13.045	10.551	2.837	9.978	9.811	7.542
	(1.36)	(2.96)	(2.53)	(2.63)	(0.62)	(2.21)	(1.80)	(1.78)
Uncertainty Index	−0.835	−4.184	−5.861	−3.627	0.043	−0.374	0.611	0.094
	(−1.04)	(−5.28)	(−6.14)	(−4.88)	(0.05)	(−0.46)	(0.63)	(0.12)
Uncertainty Index ×	17.900	20.845	28.113	22.286	6.530	6.073	6.106	6.236
Announcement	(4.10)	(4.84)	(5.42)	(5.52)	(1.94)	(1.83)	(1.53)	(2.00)
Adj. R^2	0.33%	1.03%	1.27%	1.05%	0.06%	0.19%	0.14%	0.17%

of a currency that enters a portfolio at t and exits at $t+1$ is computed as $rx_{t+1}^{\text{long}} = fw_t^{\text{bid}} - s_{t+1}^{\text{ask}}$ for a long position and $rx_{t+1}^{\text{short}} = -fw_t^{\text{ask}} + s_{t+1}^{\text{bid}}$ for a short position.

The results are reported in Table X. Even though mean returns are lower than those reported in Panel C of Table II, our results remain qualitatively the same: mean returns are increasing in interest rate differentials and are significant for all portfolios except pf1 (as illustrated by asymptotic t-statistics as well as bootstrap confidence intervals). For instance, average announcement-

Table X

Currency Portfolio Returns Net Transaction Costs on Announcement Days

This table reports summary statistics for currency portfolio returns on announcement days net of transaction costs. Portfolios are sorted according to their interest rate differentials, with "pf1" and "pf3" denoting the portfolio with the lowest and highest interest rate differential vis-à-vis the United States, respectively. "dol" denotes the portfolio that is short the U.S. dollar and long all other currencies. "S1" and "S2" are the improved trading strategies constructed in Subsection III.C. "bootstrap CI" indicates the 95% bootstrapped confidence interval. "SR" is the Sharpe ratio. All numbers are expressed in daily bps except for Sharpe ratios, which are annualized, taking into account the annual frequency of FOMC announcements (8/252). Returns are sampled from 4 pm to 4 pm ET and cover the period January 1, 1994, to December 31, 2013.

	pf1	pf2	pf3	dol	S1	S2
Mean	2.129	9.671	12.246	8.015	15.708	19.154
t-stat	(0.44)	(2.02)	(2.10)	(1.69)	(3.29)	(3.50)
Bootstrap CI	[−7.16, 11.97]	[0.75, 19.37]	[1.13, 23.83]	[0.07, 17.58]	[6.83, 25.35]	[8.85, 30.40]
Skewness	1.490	1.544	1.306	1.761	1.750	1.571
Kurtosis	7.183	10.101	8.307	9.567	8.655	8.038
SR	0.097	0.451	0.470	0.377	0.735	0.783

day returns for pf2 and pf3 are 9.67 bps and 12.24 bps, respectively, both of which are statistically significant at the 5% level. As expected, the average returns of the improved trading strategies S1 and S2 are even higher and more statistically significant.

E.3. Truncated Data

Given that currency returns occasionally experience large crashes and some announcements are more anticipated than others, one may suspect that our results are driven by a few outliers. To test for the sensitivity of our results to such outliers, we study announcement- and nonannouncement-day returns after discarding the top and bottom percentiles of the data. The results are reported in Table XI. We find virtually no distinction between the means and standard deviations of truncated and nontruncated samples (reported in Table II) across interest rate-sorted portfolios.

E.4. Bootstrapped Standard Errors and Random Sampling

Bootstrapped Standard Errors: A natural concern for the results reported in Table III is that, due to the small number of announcement days (160 in our sample), asymptotic theory may not provide a good approximation for the distribution of the estimates. We address this concern with a bootstrap exercise, in which we compute the small-sample standard errors and confidence intervals of the point estimates in our baseline regression. In particular, we draw with replacement from the empirical distribution of returns on all days, run regression (6), and store the estimated coefficients for each portfolio. The resulting distributions have means that are virtually the same as the estimated

Table XI
Summary Statistics for Currency Portfolio Returns for Truncated Data

This table reports summary statistics for currency portfolios for nonannouncement (Panel A) and announcement days (Panel B) for a truncated sample after removing the bottom and top 1% of the sample. Portfolios are sorted according to their interest rate differentials, with "pf1" and "pf3" denoting the portfolio with the lowest and highest interest rate differential vis-à-vis the United States, respectively. "dol" denotes the portfolio that is short the U.S. dollar and long all other currencies. "SR" is the Sharpe ratio. All numbers are expressed in daily bps except for Sharpe ratios, which are annualized, taking into account the annual frequency of FOMC announcements (8/252). "diff" indicates the difference between announcement- and nonannouncement-day returns in bps, with the corresponding t-statistic for a test of the difference in means between announcement and nonannouncement days reported in parentheses. Returns are sampled from 4 pm to 4 pm ET and cover the period January 1, 1994, to December 31, 2013.

	pf1	pf2	pf3	dol
Panel A: Nonannouncement Days ($n = 4,421$)				
Mean	−0.508	0.202	1.947	0.537
t-stat	(−0.67)	(0.27)	(2.22)	(0.77)
Skewness	0.131	−0.136	−0.193	−0.034
Kurtosis	3.280	3.533	4.088	3.485
SR	−0.156	0.063	0.516	0.179
Panel B: Announcement Days ($n = 157$)				
Mean	4.817	13.387	13.520	10.800
t-stat	(1.00)	(2.94)	(2.45)	(2.35)
Skewness	1.361	1.230	1.262	1.705
Kurtosis	6.617	7.582	7.116	8.869
SR	0.224	0.657	0.549	0.525
diff	5.325	13.185	11.573	10.262
	(1.29)	(3.26)	(2.43)	(2.69)

coefficients for α_1 reported in Panel A of Table III, with bootstrapped confidence intervals that never encompass zero, except for pf1.

Random Sampling from the Distribution of Nonannouncement-Day Returns: In another bootstrap exercise, we assess the likelihood of observing an average return as large as average announcement-day returns in a sample drawn from the empirical distribution of returns on all other days. More specifically, we draw with replacement a time series with length equal to the number of announcement days (160) from the empirical distribution of returns on nonannouncement days. Table XII reports the associated likelihoods for the entire day and the pre- and postannouncement windows. As can be seen, except for the total and preannouncement returns of pf1, all values are below 5%, indicating that the likelihood of earning equally large returns on nonannouncement days as on announcement days is small. The table also shows that this pattern remains unchanged regardless of whether transactions costs are taken into account.

Table XII

Bootstrap Exercise for Currency Portfolios

This table reports the likelihood of observing an average return as large as average announcement-day returns in a sample drawn from the empirical distribution of returns on nonannouncement days. Portfolios are sorted according to their interest rate differentials, with "pf1" and "pf3" denoting the portfolio with the lowest and highest interest rate differential vis-à-vis the United States, respectively. "dol" denotes the portfolio that is short the U.S. dollar and long all other currencies. "entire day", "pre-ann", and "post-ann" correspond to 4 pm–4 pm, 4 pm–215 pm, and 215 pm–4 pm, respectively. The data run from January 1, 1994, to December 31, 2013.

	Before Transaction Costs				Ex Transaction Costs			
	pf1	pf2	pf3	dol	pf1	pf2	pf3	dol
Entire day	9.13%	0.16%	0.58%	0.46%	9.31%	0.16%	0.58%	0.48%
Pre-ann.	18.48%	0.56%	2.48%	2.00%	18.41%	0.56%	2.48%	2.07%
Post-ann.	1.53%	2.05%	1.19%	0.60%	2.48%	3.05%	1.37%	0.88%

E.5. Other Macroeconomic Announcements

Are other macroeconomic announcements able to generate equally large returns as those earned on FOMC announcement days? To answer this question, we consider three major U.S. macroeconomic news releases: total nonfarm payroll employment, the Producer Price Index, and the Consumer Price Index, all published by the Bureau of Labor Statistics (BLS). We build the corresponding announcement-day dummy variables and rerun regression (6) for each of these announcements separately.

Table XIII

Currency Portfolio Returns for Other Macroeconomic Announcements

This table reports excess returns on announcement and nonannouncement days for nonfarm payroll employment, CPI, and PPI. Portfolios are sorted according to their interest rate differential, with "pf1" and "pf3" denoting the portfolio with the lowest and highest interest rate differential vis-à-vis the United States, respectively. "dol" denotes the portfolio that is short the U.S. dollar and long all other currencies. "diff" indicates the difference between announcement- and nonannouncement-day returns in bps, with the corresponding t-statistic for a test of the difference in means between announcement and nonannouncement days reported in parentheses. The sample covers January 1, 1994, to December 31, 2013.

	Nonfarm Payroll				Consumer Price Index				Producer Price Index			
	pf1	pf2	pf3	dol	pf1	pf2	pf3	dol	pf1	pf2	pf3	dol
Ann.	−6.523	1.824	4.783	0.028	2.220	2.316	3.292	2.609	3.708	5.311	6.861	5.293
	(−1.60)	(0.46)	(1.12)	(0.01)	(0.56)	(0.59)	(0.66)	(0.68)	(1.00)	(1.62)	(1.75)	(1.66)
Non.	−0.386	0.497	2.459	0.857	−0.336	0.818	2.351	0.945	−0.446	0.478	2.127	0.719
	(−0.47)	(0.62)	(2.54)	(1.14)	(−0.41)	(1.02)	(2.43)	(1.25)	(−0.55)	(0.59)	(2.20)	(0.96)
diff	−6.137	1.327	2.324	−0.829	2.556	1.498	0.940	1.665	4.154	4.833	4.734	4.574
	(−1.48)	(0.33)	(0.53)	(−0.22)	(0.63)	(0.38)	(0.19)	(0.43)	(1.10)	(1.43)	(1.17)	(1.40)

The results are reported in Table XIII. As the table illustrates, the difference between returns on announcement and nonannouncement days is never statistically different from zero for any of the announcements or interest rate-sorted portfolios. This evidence thus suggests that monetary policy announcements by the Federal Reserve have a unique impact on currency returns that is not shared by other macroeconomic announcements.

IV. Conclusions

In this paper, we document that returns to a strategy that is short the U.S. dollar and long other currencies are on average an order of magnitude larger on days that the FOMC makes a monetary policy announcement compared to nonannouncement days. This difference is increasing in the forward discount of the currency and becomes larger when the Fed adopts a policy of monetary easing. Moreover, using different proxies for monetary policy uncertainty, we find that currency returns increase when uncertainty is higher.

We interpret these observations through the lens of a minimalistic model of exchange rate determination in imperfect financial markets. Exchange rates in our model are determined by the risk-bearing capacity of financiers who intermediate global demand for currencies. Within this framework, we show that an increase in monetary policy uncertainty due to an impending FOMC announcement increases foreign currencies' excess returns as compensation to financiers who bear this extra risk. We also show that, consistent with our empirical results, these risk premia are increasing in the foreign currency's interest rate differential vis-à-vis the United States. Finally, our model predicts that the actual realization of the monetary policy shock at the announcement impacts currency excess returns, with an expansionary (contractionary) policy resulting in higher (lower) returns, a prediction that is in line with what we document empirically.

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Appendix A: Proofs and Derivations

Throughout the proofs, we use G to denote the common cumulative distribution function of f_t and use F to denote the standardized (i.e., demeaned and normalized) distribution of $\log(R_1)$. For notational simplicity, we use H to denote the distribution of $f_1 + R_1^{-1}G^{-1}(\alpha_1)$. Note that this distribution can be explicitly expressed in terms of F and G.

LEMMA A1: *The representative financier's equilibrium positions are given by*

$$Q_0 = \frac{R^{*2}H^{-1}(\alpha_0) - R_0 f_0(1+R^*)}{R_0\left(1+R^*+R^{*2}\right)}, \tag{A1}$$

$$Q_1 = \frac{R^* G^{-1}(\alpha_1) + R_1(R_0 Q_0 - f_1)}{R_1(R^* + 1)}, \tag{A2}$$

where $H(x) = \mathbb{P}(f_1 + R_1^{-1} G^{-1}(\alpha_1) \le x)$.

PROOF: Recall from (2) that, at period $t \in \{0, 1\}$, the representative financier maximizes her expected profits $\mathbb{E}_t[V_{t+1}]$, subject to the value-at-risk constraint $\mathbb{P}_t(V_{t+1} \le -\epsilon) \le \alpha_t$, while taking the exchange rates as given. Suppose that $R^*\mathbb{E}_t[e_{t+1}] > R_t e_t$, a statement that we will verify later. Under this assumption, the financier chooses as large a Q_t as possible. At the same time, it is immediate that increasing Q_t tightens the financier's value-at-risk constraint, which means that the constraint has to bind in equilibrium. Thus, as $\epsilon \to 0$, we have

$$\mathbb{P}_t\left(R^* e_{t+1} \le R_t e_t\right) = \alpha_t. \tag{A3}$$

Setting $t = 1$ and substituting for the exchange rates in the above equation from the market-clearing conditions (4) and (5) implies that

$$\mathbb{P}\left(f_2 \le R_1 Q_1 + R_1(f_1 + Q_1 - R_0 Q_0)/R^*\right) = \alpha_1.$$

Replacing the left-hand side of the above equation with $G(R_1 Q_1 + R_1(f_1 + Q_1 - R_0 Q_0)/R^*)$ and solving for Q_1 leads to (A2). To verify that Q_1 is indeed positive, note that $R^* G^{-1}(\alpha_1) \ge R^* \underline{f} \ge R_1 f_1$. Thus, Q_1 is positive as long as Q_0 is positive, which we verify below.

To obtain the expression for Q_0 in equation (A1), set $t = 0$ in (A3), replace Q_1 from (A2) in terms of Q_0, and substitute for e_0 and e_1 from the market-clearing conditions (3) and (4). Following these steps implies that

$$\mathbb{P}\left(f_1 + R_1^{-1} G^{-1}(\alpha_1) \le R_0 Q_0 + R_0(R^* + 1)(f_0 + Q_0)/R^{*2}\right) = \alpha_0.$$

Replacing the left-hand side of the above equation with $H(R_0 Q_0 + R_0(R^* + 1)(f_0 + Q_0)/R^{*2})$ and solving for Q_0 thus leads to (A1). To verify that $Q_0 \ge 0$, note that $H^{-1}(0) \ge \underline{f}(1 + 1/R^*)$, which, together with the assumption that $R^* \underline{f} > R_t \overline{f}$, guarantees that $R^{*2} H^{-1}(\alpha_0) > R_0 f_0 (1 + R^*)$.

The proof is complete once we verify that $\Delta_t = R^*\mathbb{E}_t[e_{t+1}] - R_t e_t$ is indeed positive in equilibrium. Substituting for e_1, e_2, Q_0, and Q_1 from equations (4), (5), (A1), and (A2) implies that

$$\Delta_1 = R^*\mathbb{E}_1[e_2] - R_1 e_1 = R^* d^{-1}\Big(\mathbb{E}_1[f_2] - G^{-1}(\alpha_1)\Big). \tag{A4}$$

It is immediate that the right-hand side of the above equality is positive for small enough values of α_1. In fact, it is simply sufficient for α_1 to be smaller than $G(\mathbb{E}[f_2]) = \mathbb{P}(f_2 \le \mathbb{E}_1[f_2])$. Similarly, substituting for e_0 and e_1 from the market-clearing conditions (3) and (4) implies that

$$\Delta_0 = R^*\mathbb{E}_0[e_1] - R_0 e_0 = \tfrac{R^{*2} d^{-1}}{R^* + 1}\Big(\mathbb{E}_0[f_1] + \mathbb{E}_0[R_1^{-1}] G^{-1}(\alpha_1) - H^{-1}(\alpha_0)\Big), \tag{A5}$$

which is positive for small enough values of α_0, thus completing the proof. □

LEMMA A2: *Q_0 and Q_1 are decreasing in σ_R.*

PROOF: Recall from equation (A2) that Q_1 is increasing in Q_0, which is itself increasing in $H^{-1}(\alpha_0)$, as is evident from (A1). Therefore, it is sufficient to prove that $H^{-1}(\alpha_0)$ is decreasing in σ_R.

To this end, let $F(r)$ denote the probability that $\log(R_1)$ is r standard deviations above its mean; that is, $F(r) = \mathbb{P}(\log R_1 \leq \log R_0 + r\sigma_R)$, where, recall that by assumption, $\mathbb{E}_0[\log(R_1)] = \log(R_0)$. Therefore, if $\tilde{F}(x) = \mathbb{P}(R_1^{-1} \leq x)$ denotes the cumulative distribution function of R_1^{-1}, we have

$$\tilde{F}(x) = \mathbb{P}(\log R_1 \geq -\log x) = 1 - F\left(\tfrac{-1}{\sigma_R}\log(R_0 x)\right). \tag{A6}$$

On the other hand, the fact that R_1 and f_2 are independent implies that

$$H(x) = \mathbb{P}(f_1 + R_1^{-1}G^{-1}(\alpha_1) \leq x) = \int_{\underline{f}}^{\min\{\overline{f},x\}} \tilde{F}\left(\tfrac{x-y}{G^{-1}(\alpha_1)}\right) dG(y).$$

Setting $x = H^{-1}(\alpha_0)$ and using (A6) to replace $\tilde{F}$ in terms of F, we obtain

$$\int_{\underline{f}}^{\min\{H^{-1}(\alpha_0),\overline{f}\}} \left[1 - F\left(\frac{1}{\sigma_R}\log\left(\frac{G^{-1}(\alpha_1)}{R_0(H^{-1}(\alpha_0) - y)}\right)\right)\right] dG(y) = \alpha_0. \tag{A7}$$

Differentiating both sides with respect to σ_R and using the Leibniz integral rule leads to

$$\int_{\underline{f}}^{\min\{H^{-1}(\alpha_0),\overline{f}\}} \frac{\partial}{\partial\sigma_R} F\left(\frac{1}{\sigma_R}\log\left(\frac{G^{-1}(\alpha_1)}{R_0(H^{-1}(\alpha_0) - y)}\right)\right) dG(y) = 0, \tag{A8}$$

for all σ_R, where recall that even though $H^{-1}(\alpha_0)$ depends on the extent of monetary policy uncertainty, α_0 is a fixed parameter of the model that is independent of σ_R.

Now suppose that $H^{-1}(\alpha_0)$ is increasing in σ_R for some constellation of parameters. Under such an assumption, the integrand in (A8) would be negative, as a higher σ_R would only decrease $\frac{1}{\sigma_R}\log(\frac{G^{-1}(\alpha_1)}{R_0(H^{-1}(\alpha_0)-y)})$. But this violates equation (A8), which requires that the integral equal zero. Therefore, $H^{-1}(\alpha_0)$ is decreasing in σ_R for all σ_R. □

PROOF OF PROPOSITION 1: Recall that the foreign currency's total expected excess return is given by

$$\begin{aligned}\mathbb{E}_0[\phi] &= 2\log(R^*) - \mathbb{E}_0[\log(R_1)] - \log(R_0) + \mathbb{E}_0[\log(e_2)] - \log(e_0)\\ &= 2\log(R^*) - 2\log(R_0) + \mathbb{E}_0[\log(f_2 - R_1 Q_1)] - \log(f_0 + Q_0),\end{aligned}$$

where we are substituting for e_0 and e_2 from the market-clearing conditions (3) and (5) and using the fact that $\mathbb{E}_0[\log(R_1)] = \log(R_0)$. By Lemma A2, we have that Q_0 and Q_1 are decreasing in σ_R. It thus follows that the right-hand side of the above expression is increasing in σ_R. □

PROOF OF PROPOSITION 2: Market-clearing conditions (3) and (5) imply that the foreign currency's total excess returns are given by

$$\phi = \log\left(\tfrac{R^{*2}(f_2 - R_1 Q_1)}{R_1 R_0 (f_0 + Q_0)}\right).$$

Substituting for Q_0 and Q_1 from (A1) and (A2) leads to

$$\phi = \log\left(1 + \tfrac{R^{*2}+R^*+1}{R_0 f_0 + H^{-1}(\alpha_0)}\left(\tfrac{f_2 - G^{-1}(\alpha_1)}{R_1} + \tfrac{f_1 + R_1^{-1}G^{-1}(\alpha_1) - H^{-1}(\alpha_0)}{R^*+1}\right)\right),$$

which implies that

$$\mathbb{E}_0[\phi] = \frac{R^{*2}+R^*+1}{R_0 f_0 + H^{-1}(\alpha_0)}\left(\mathbb{E}_0\left[R_1^{-1}\right]\left(\mathbb{E}_0[f_2] - G^{-1}(\alpha_1)\right)\right.$$
$$\left. + \frac{\mathbb{E}_0[f_1] + \mathbb{E}_0[R_1^{-1}]G^{-1}(\alpha_1) - H^{-1}(\alpha_0)}{R^*+1}\right)$$

up to a first-order approximation. The fact that Δ_1 and Δ_1 given in (A5) and (A4) are positive guarantees that $\mathbb{E}_0[\phi]$ is increasing in R^*. In particular,

$$\frac{\partial \mathbb{E}_0[\phi]}{\partial R^*} = \frac{d\Delta_1(2R^*+1)\mathbb{E}_0[R_1^{-1}]}{R^*(R_0 f_0 + H^{-1}(\alpha_0))} + \frac{d\Delta_0 {R^*}^{-1}(R^*+2)}{(R^*+1)(R_0 f_0 + H^{-1}(\alpha_0))}, \tag{A9}$$

which is always positive.

To prove the second statement, note that the first term on the right-hand side of (A9) is decreasing in $H^{-1}(\alpha_0)$, which is itself decreasing in σ_R (as proved in Lemma A2). Consequently, the first term on the right-hand side of (A9) is increasing in σ_R. As for the second term, note that its denominator is increasing in $H^{-1}(\alpha_0)$, whereas Δ_0 defined in (A5) is decreasing in $H^{-1}(\alpha_0)$. As a result, the second term on the right-hand side of (A9) is also decreasing in $H^{-1}(\alpha_0)$ and hence is increasing in σ_R. Taken together, these observations imply that $\partial^2\mathbb{E}_0[\phi]/\partial R^*\partial\sigma_R$ is positive. □

PROOF OF PROPOSITION 3: Recall that, by definition, $\phi_2 = \log(R^* e_2) - \log(R_1 e_1)$. Substituting for e_1 and e_2 from the market-clearing conditions (4) and (5) implies that

$$\phi_2 = \log\left(1 + \tfrac{(R^*+1)(f_2 - G^{-1}(\alpha_1))}{G^{-1}(\alpha_1) + R_1(f_1 - R_0 Q_0)}\right),$$

where we are also using (A2) to replace Q_1 in terms of Q_0. Therefore,

$$\mathbb{E}_1[\phi_2] = \frac{(R^*+1)(\mathbb{E}_1[f_2] - G^{-1}(\alpha_1))}{G^{-1}(\alpha_1) + R_1(f_1 - R_0 Q_0)} \tag{A10}$$

up to a first-order approximation. Recall from the proof of Lemma A1 that Δ_1 is positive. Therefore, $\mathbb{E}_1[\phi_2]$ is decreasing in R_1 as long as $f_1 > R_0 Q_0$. To verify this inequality, note that

$$f_1 - R_0 Q_0 = \tfrac{1}{R^{*2}+R^*+1}\left(f_1(R^{*2}+R^*+1) + R_0 f_0(1+R^*) - R^{*2}H^{-1}(\alpha_0)\right),$$

where we are using equation (A1). It is now immediate that the right-hand side of the above equation is positive for small enough values of α_0, thus establishing that $\mathbb{E}_1[\phi_2]$ is decreasing in R_1.

To prove the second statement, note that (A10) implies

$$\frac{\partial \mathbb{E}_1[\phi_2]}{\partial R_1} = \frac{(R^* + 1)(\mathbb{E}_1[f_2] - G^{-1}(\alpha_1))(R_0 Q_0 - f_1)}{\left(G^{-1}(\alpha_1) + R_1 f_1 - R_1 R_0 Q_0\right)^2}.$$

Furthermore, recall from Lemma A2 that Q_0 is decreasing in σ_R. Therefore, it is immediate that increasing σ_R reduces the numerator while increasing the denominator, thus implying that the right-hand side of the above equality is decreasing in σ_R. □

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1: Internet Appendix.