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JEL Classification: E52, E58, F31.

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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 also show that these excess returns (i) are higher for currencies with higher interest rate differentials vis-à-vis the U.S.; (ii) increase with uncertainty about monetary policy; and (iii) intensify when the Federal Reserve adopts a policy of monetary easing. We interpret these excess returns as a compensation for monetary policy uncertainty within a parsimonious model of constrained financiers who intermediate global demand for currencies.

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1 Introduction

Announcements by the Federal Open Market Committee (FOMC), which occur regularly at prespecified dates, are one of the most highly anticipated events by investors around the world. Through these announcements, the Federal Reserve communicates monetary policy in the form of setting the target federal funds rate.

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. Indeed, this was illustrated recently by the announcement on March 18, 2015, when the Australian dollar appreciated more than 2% against the U.S. dollar within a few hours in the run-up to the announcement (corresponding to a three standard deviation daily change), followed by a 1.6% depreciation right after the announcement. The active nature of the currency markets (with a daily turnover of over USD 5 trillion), coupled with high market concentration and the participants' ability to operate with very high leverage ratios means that even small price movements in this market can translate into economically significant effects.[1,2]

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. More specifically, 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 excess returns on days with scheduled FOMC announcements relative to non-announcement days. Crucially, the excess returns earned by following such a strategy span the entire announcement day, consisting of a pre- as well as a post-announcement component. We also document that these excess returns (i) are higher for currencies with higher interest rate differentials vis-à-vis the U.S.; (ii) increase with market participants' uncertainty about monetary policy; and (iii) intensify when the Fed 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 trades, 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 limited commitment frictions or value-at-risk constraints.[3] Crucially, in addition to the "fundamental risk" in global demand and supply for currencies, financiers in our model also face "monetary policy uncertainty" due to potential future changes in interest rates.

Based on this framework, we show that an increase in uncertainty regarding future interest rates

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[1] Citibank and Deutsche Bank hold over 30% of the market share.

[2] According to the Bank for International Settlements (2015), USD 364 billion are traded daily in the AUD-USD market. Therefore, as a back-of-the-envelope calculation, a 2% appreciation of the Australian dollar against the U.S. dollar (as observed before the March 2015 FOMC announcement) results in a USD 7.28 billion move, which given the high leverage ratios — a 1% margin is typical — implies a USD 728 billion movement in investors' balance sheets within hours.

[3] Our baseline model presented in Section 2 assumes that financiers are subject to a limited commitment constraint as in Gabaix and Maggiori (2015). In the Appendix, we provide an alternative model with value-at-risk constraints and show that all our results remain virtually the same.

in the U.S. results in higher excess returns for other currencies: the financiers are willing to engage in currency trade and 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, coupled with 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 U.S. This is due to the fact that even though a larger 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 exchange rate differential one for one, thus resulting in higher overall excess returns.

The fact that higher currency excess returns are meant to compensate financiers for the uncertainty in monetary policy means that such returns are materialized irrespective of the interest rates set by the Fed following the announcement. As such, we interpret the impact of monetary policy uncertainty on currency excess returns as a "pre-announcement" effect. In addition to this effect, however, the actual realization of the monetary policy shock also impacts the foreign currencies' excess returns by affecting the financiers' balance sheets, leading to what we call a "post-announcement" effect. Indeed, we show that within our model, an ex post adoption of an expansionary monetary policy (corresponding to an interest rate reduction by the Fed) further increases foreign currencies' excess returns.

To empirically study currency risk premia around announcement days, we use 20 years of high-frequency data for the ten 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 economically significant returns on announcement days compared to non-announcement days. Furthermore, we document that returns earned on the eight announcement days account for a significant fraction of the currencies' yearly excess returns. Crucially, we also find that in contrast to the equity index market, currencies exhibit excess returns that span the entire announcement day, consisting of a pre- and a post-announcement component, as predicted by our model.

Since investors do not typically trade in individual currencies but rather go long and short a portfolio of currencies simultaneously, we also test our model's predictions for currency portfolios sorted based on their forward discounts. 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 5.71 basis points (bps) during days when the Federal Reserve makes an announcement, compared to an average of -0.55bps on all other days. This difference becomes larger for the portfolio consisting of high interest rate currencies, with a daily return of 16.83bps on announcement days compared to 1.66bps on non-announcement days. This 15.17bps difference is not only highly statistically significant (with a t-statistic of 2.43), but also translates into economically meaningful returns. In particular, the fact that even a retail investor in FX markets can take leverage ratios of up to 100 to 1 (or trade on a 1% margin) means that holding the high interest rate currency portfolio for the eight announcement days during the year yields a 136% annual return on a USD 100 investment.[4]

Our explanation for these large returns around announcement days is that they reflect a premium for heightened monetary policy uncertainty or more generally a tightening of financiers' risk-bearing capacity. Using different proxies for monetary policy uncertainty (such as an implied volatility index from Treasury futures options and an uncertainty measure constructed from survey forecasts about the future federal funds rate), we find that an increase in market participants' uncertainty is indeed associated with higher returns around FOMC announcement days.

We then focus on the so called post-announcement effect by testing the impact of the realization of monetary policy shocks on currency returns. Using a monetary policy indicator constructed from high-frequency data on five-year Treasury futures, we find that the largest returns are materialized during announcement days when the Fed adopts an expansionary monetary policy. This result, which is robust to using alternative measures for the stance of monetary policy, is consistent with our theoretical framework which predicts that currency excess returns should increase even further when the federal funds rate is decreased.

To test whether similar effects exist for other central banks, we collect the exact timing of monetary policy announcements for the different countries in our sample. We find a very strong effect for announcements made by the Bank of Japan, with a pattern that is virtually identical to that of the FOMC. However, we find no significant effect for other central banks.

We conclude the paper by running a series of robustness checks. First, we redo the analysis for winsorized data to ensure that our results are not driven by outliers in the sample. Second, to overcome concerns regarding the sample size, we compute small sample standard errors through a bootstrap exercise. In another bootstrap exercise, we sample randomly from the distribution of non-announcement returns to test whether we can generate returns similar in size to those observed on announcement dates. These exercises all indicate that our empirical results are robust and economically meaningful. Finally, we show that our trading strategy is highly profitable (with annualized Sharpe ratios of up to 0.5) even when, by adjusting for bid-ask spreads, transaction costs are taken into account.

Related Literature: 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 as a response to revisions to expectations about short-term interest rates. Similarly, Jones, Lamont, and Lumsdaine (1998) study realized bond excess returns around macroeconomic news releases (inflation and 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 Future options to assess how state price density changes around macroeconomic announcements; and Savor and

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[4] A start capital of USD 100 yields an investment of USD $10,000$, thus obtaining $10,000 \times 1.0017^8 = 10,136$. This is a significantly larger rate of return compared to the equity market, where Lucca and Moench (2015) report a 50bps return per announcement. Since typical leverage ratios in equity markets are around 2 to 1, this would imply a 8% return.

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&P 500 index returns ahead of scheduled announcements and find that the unconditional announcement day returns are due to a pre-FOMC drift rather than returns earned at the announcement.[5]

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, thus consisting of a pre- as well as a post-announcement component. Second, we also observe significant differences in returns depending on the direction of the interest rate change adopted by the Fed. Finally, we provide a theoretical framework that interprets the documented pre- and post-announcement excess returns as, respectively, a compensation for intermediaries' exposure to monetary policy uncertainty prior to announcements and the ex post impact of the monetary policy shock on their balance sheets.

Our paper is related to the theoretical asset pricing literature that studies the interplay of 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 affects 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 an uncertainty plays a first-order role in determining currency excess returns prior to central bank announcements.

Outline: The rest of the paper is organized as follows. In the next section, we formulate a model of exchange rate determination around central bank announcement days. Section 3 describes the data on which we base our analysis. Our main empirical findings are presented in Section 4. Section 5 concludes. An alternative theoretical framework and the proofs are presented in the Appendix.

2 Theoretical Framework

In this section, we present a parsimonious model of exchange rate determination that forms the basis of our analysis. Our model builds on the recent framework of Gabaix and Maggiori (2015) by allowing for monetary policy uncertainty.

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[5] In parallel, a large empirical literature, going back to Fleming and Remolona (1999) and Andersen, Bollerslev, Diebold, and Vega (2003), 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.

2.1 Model

Consider a discrete-time economy that lasts for two periods $t = 0, 1$. The economy consists of two countries, each populated with 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 risk-free bond that is denominated in their domestic currency. We use R and R^* to denote the interest rates in the United States and the foreign country, respectively, and define the exchange rate e_t as the quantity of dollars that can be bought by one unit of the foreign currency at time t.

At any given period, investors in each country have a downward-sloping demand for assets denominated in the other country's currency. More specifically, 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 $-f_t$ in dollars. Similarly, we assume that foreign investors have a time t demand of $d_t e_t$ for dollar-denominated assets, funded by the offsetting position $-d_t$ in their currency.[6]

In addition to the investors, the economy is populated by a unit mass of identical, risk-neutral financiers. Unlike the investors, these financiers can trade in the domestic bonds of both countries. As such, their 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, which implies that her balance sheet at the end of $t = 0$ consists of $-Q$ dollars and Q/e_0 units of the foreign currency.[7] Consequently, the representative financier's expected profit (expressed in dollars) is given by

$$\mathbb{E}[V] = \mathbb{E}\left[\frac{e_1}{e_0}R^* - R\right]Q, \tag{1}$$

where recall that R and R^* denote the interest rates in the U.S. and the foreign country, respectively.

As our main point of departure from the framework of Gabaix and Maggiori (2015), we assume that financiers may be uncertain about the interest rate in the U.S. when taking their positions. Formally, we assume that R is a random variable, with mean $\mathbb{E}[R]$ and standard deviation σ_R, whose realization is determined at $t = 1$. This assumption captures the idea that, prior to an FOMC announcement, agents may be uncertain about the future stance of monetary policy, in which case $\sigma_R > 0$. On the other hand, $\sigma_R = 0$ during "normal" periods with no scheduled monetary policy announcements, as agents are certain that the interest rate will remain unchanged within the period.

An immediate implication of equation (1) is that whenever the uncovered interest rate parity (UIP) condition is not satisfied (i.e., $\mathbb{E}[R^* e_1/e_0 - R] \neq 0$), each financier takes infinitely large positions in one of the currencies, unless some friction limits her ability to do so. We model the presence of such intermediation frictions by assuming that financiers are subject to a limited commitment constraint: at the end of $t = 0$, each financier can divert a fraction ω of the funds, which cannot be recovered by her lenders. This constraint implies that the financier can hold a position of size Q/e_0 in

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[6] Such demand may arise due to various reasons, such as trade or portfolio flows.

[7] As we show later on, our assumptions guarantee that the representative financier always shorts the dollar, i.e., $Q \geq 0$.

the foreign currency only if her expected profits are large enough to guarantee that she does not divert the funds; that is, $\mathbb{E}[V] \geq \omega Q$. Following Gabaix and Maggiori (2015), we assume that the divertable fraction is given by $\omega = \Gamma Q/e_0$, where $\Gamma = \gamma \text{var}(e_1)$ for some constant $\gamma \geq 0$. This assumption captures the idea that the financier's outside option increases in the "complexity" — that is, the size and volatility — of her position.[8]

To summarize, the representative financier faces the following optimization problem:

$$\begin{aligned} \max_{Q} \quad & \mathbb{E}[V] \\ \text{s.t.} \quad & \mathbb{E}[V] \geq \Gamma Q^2/e_0, \end{aligned} \tag{2}$$

where $V = (R^* e_1/e_0 - R)\, Q$ and Γ captures the financier's "risk-bearing capacity." When $\Gamma = 0$, the financier is unconstrained and can take arbitrarily large currency positions. However, as Γ increases (for example, due to an increase in the anticipated volatility of future exchange rates), the financier's outside option becomes more attractive, which in turn reduces her ability to borrow from the investors.

The equilibrium of the simple economy described above is defined in a straightforward manner. It consists of the tuple (e_0, e_1, Q) of exchange rates and currency positions such that (i) the representative financier chooses Q in order to maximize her expected profit, taking the exchange rates as given; and (ii) the currency market clears. In particular, the net demand for dollars is equal to zero in both periods:

$$d_0 e_0 - f_0 - Q = 0 \tag{3}$$

$$d_1 e_1 - f_1 + RQ = 0. \tag{4}$$

Note that for the market clearing condition (4) we are assuming that the representative financier unwinds her dollar position by purchasing RQ dollars at the end of $t = 1$ and keeps her profits (or losses) in the foreign currency.

2.2 Equilibrium Exchange Rates

We now provide a characterization of equilibrium exchange rates in the economy described above. Throughout, we assume that d_t is deterministic and constant over time, i.e., $d_1 = d_0 = d$. Furthermore, we assume that f_1 is independent of R and that $\mathbb{E}[f_1] = f_0$. These assumptions have no bearing on the model's economic insights, though they simplify the algebraic expressions considerably. Finally, we assume that the expected interest rate in the U.S. is smaller than that of the foreign country's (that is, $\mathbb{E}[R] < R^*$), an assumption that implies that the dollar and the foreign currency serve as the funding and investment currencies, respectively.

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[8] We model the presence of frictions in our baseline framework by means of a limited commitment constraint. However, our model's main insights hold more generally and are not sensitive to the specific nature of this constraint. In particular, any constraint that induces a downward-sloping demand curve for risk taking by financiers results in similar implications. In Appendix A, we show that the model's insights remain unchanged if we instead assume that the financiers are subject to a value-at-risk constraint.

To characterize the equilibrium, recall that the representative financier chooses her position Q in order to maximize her expected profit, subject to the limited commitment constraint. It is easy to verify that the constraint in (2) always binds. As a result,

$$Q = \frac{1}{\Gamma}\mathbb{E}\left[R^* e_1 - R e_0\right]. \tag{5}$$

Replacing for Q in the market clearing conditions (3) and (4) from the above equation thus implies that the financier's short position in the dollar is

$$Q = \frac{f_0\left(R^* - \mathbb{E}[R]\right)}{\Gamma d + (1+R^*)\mathbb{E}[R]} \tag{6}$$

and that equilibrium exchange rates are given by

$$e_0 = d^{-1} f_0 + d^{-1} f_0 \left(\frac{R^* - \mathbb{E}[R]}{\Gamma d + (1+R^*)\mathbb{E}[R]}\right) \tag{7}$$

$$e_1 = d^{-1} f_1 - R d^{-1} f_0 \left(\frac{R^* - \mathbb{E}[R]}{\Gamma d + (1+R^*)\mathbb{E}[R]}\right). \tag{8}$$

These equations illustrate that the financiers' risk-bearing capacity plays a key role in determining equilibrium exchange rates. For instance, a reduction in the financiers' risk-bearing capacity (that is, an increase in Γ) restricts their ability to take larger positions by tightening their constraints, which in turn results in dollar's appreciation at $t = 0$ and a depreciation at $t = 1$. On the other hand, when $\Gamma = 0$, financiers face no risk constraints, and hence are willing to take infinitely large positions whenever expected returns of shorting the dollar are positive. As a result, the risk premium on the foreign currency is entirely eliminated in equilibrium. Indeed, equations (7) and (8) imply that if $\Gamma = 0$, then $\mathbb{E}[R^* e_1/e_0] = \mathbb{E}[R]$, which means that UIP is satisfied.

We end this discussion by remarking that financiers' risk-bearing capacity is itself an endogenous variable. Therefore, to complete the characterization of equilibrium, we next relate Γ to the exogenous parameters of the model. From (8), it is easy to see that exchange rate volatility at $t = 1$ is

$$\text{var}(e_1) = d^{-2}\left(\sigma_f^2 + \left(\frac{b}{\Gamma + c}\right)^2 \sigma_R^2\right), \tag{9}$$

where $b = d^{-1} f_0 (R^* - \mathbb{E}[R])$ and $c = d^{-1}(1 + R^*)\mathbb{E}[R]$. This equation, coupled with the fact that $\Gamma = \gamma \text{var}(e_1)$, implies that the representative financier's risk-bearing capacity is determined as the solution to the following equation:

$$d^2 \Gamma = \gamma \sigma_f^2 + \gamma \left(\frac{b}{\Gamma + c}\right)^2 \sigma_R^2, \tag{10}$$

thus completing the characterization. In addition, equation (10) illustrates that the risk-bearing capacity of the financiers depends on both "fundamental volatility" (that is, volatility in the investors' demand for and supply of currencies, captured in our model by σ_f^2) and monetary policy uncertainty (captured by σ_R^2). As a result, as we show in the next subsection, an increase in either type of uncertainty tightens the financiers' constraint with first-order implications for equilibrium exchange rates and excess returns.

2.3 Monetary Policy Uncertainty

We now characterize how uncertainty about the future stance of monetary policy in the U.S. impacts the foreign currency's excess returns, $\phi = R^* e_1/(Re_0)$. We start our analysis with a simple lemma:

Lemma 1. $\partial\Gamma/\partial\sigma_R > 0$.

In other words, an increase in monetary policy uncertainty reduces financiers' risk-bearing capacity. This is due to the fact that any form of uncertainty (whether it is about investors' currency demand as in Gabaix and Maggiori (2015) or about interest rates), increases financiers' expectation of future exchange rate volatility at $t = 1$, thus increasing the perceived riskiness of their short position in the dollar.

The next lemma shows that a reduction in financiers' risk-bearing capacity increases the foreign currency's excess returns:

Lemma 2. $\partial\phi/\partial\Gamma > 0$.

The intuition underlying this result is also straightforward: increasing Γ tightens the financiers' constraint in (2), thus limiting the extent to which they are able to short the dollar. As a result, for currency markets to clear in both periods, the foreign currency has to depreciate at $t = 0$ and appreciate at $t = 1$, increasing its excess returns.

Noting that σ_R impacts the foreign currency's excess returns only through Γ, the juxtaposition of Lemmas 1 and 2 leads to the following proposition, which serves as our main result in this section:

Proposition 1. *An increase in monetary policy uncertainty in the U.S. increases the foreign currency's excess returns, that is,* $\partial\phi/\partial\sigma_R > 0$.

This result thus suggests that prior to FOMC announcements, excess returns on the foreign currency should be higher relative to normal periods with no pre-scheduled announcements. This is a consequence of the fact that, right before an announcement, financiers who short the dollar are subject to the risk induced by a potential change in interest rates — a risk that is above and beyond the usual risk they face during normal times. Given their downward-sloping demand for risk-taking (captured in this model by means of the limited commitment constraint), financiers are willing to bear this extra risk only if they are compensated with higher returns. These higher excess returns materialize by the foreign currency's depreciation at $t = 0$ and its appreciation at $t = 1$.

Our next result shows how the foreign currency's excess returns depend on the interest rate in the foreign country:

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

A higher interest rate in the foreign country impacts excess returns via two separate channels. First, there is the mechanical effect that increasing R^* increases the interest rate differential R^*/R between the two countries, which makes shorting the dollar more attractive. Consequently, as is evident from (6), financiers take larger positions in equilibrium. This increase in position size results in an exchange rate adjustment that reduces e_1/e_0. The key observation here is that due to financiers' limited risk-bearing capacity, the adjustment in exchange rates does not offset the increase in R^*/R one for one. As a result, the overall excess returns of the foreign currency increases in R^*.

Increasing R^* also impacts excess returns through a second channel. This channel, which is absent in the baseline framework of Gabaix and Maggiori (2015) with $\sigma_R = 0$, works through changes in financiers' risk-bearing capacity Γ. In particular, when uncertainty about monetary policy is non-trivial, the larger position Q taken by the financiers in response to a higher interest rate differential increases the anticipated exchange rate volatility at $t = 1$. As a result, a higher R^* increases Γ, which means that the financiers have to be compensated even more to be willing to bear this extra risk.

More importantly, 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 in compensation for higher monetary policy uncertainty are larger for currencies with higher interest rates.

2.4 Monetary Policy Shock

Our results thus far focused on how uncertainty about interest rates in the U.S. impacts exchange rates and excess returns. Given that this uncertainty is resolved at $t = 1$, all the effects characterized so far work through financiers' $t = 0$ expectations about future exchange rates. As our next result, we show that in addition to these expectations-driven effects, the actual realization of R also has an impact on the foreign currency's (ex post) excess returns. To capture this so called "post-announcement effect," we study how the ex post choice of interest rate by the Fed impacts excess returns, while keeping $\mathbb{E}[R]$ and σ_R constant.

We start by noting that the realization of R at $t = 1$ can have no impact on variables that are determined at $t = 0$. In fact, as is evident from equations (6) and (7), the exchange rate e_0 and the size of financiers' position Q are independent of R's realization. However, by equation (8), a rate reduction by the Fed results in a further appreciation of the foreign currency at $t = 1$. As a result, $\partial\phi/\partial R < 0$, which means that an interest rate reduction (increase) by the Fed increases (reduces) the foreign currency's excess returns. Furthermore, we have the following result:

Proposition 3. *An interest rate reduction (increase) by the Fed increases (reduces) the difference between excess returns on announcement and non-announcement days, that is,* $\partial^2\phi/\partial R\partial\sigma_R < 0$.

The juxtaposition of this result with Proposition 1 thus implies that not only the foreign currency exhibits higher excess returns on announcement days relative to non-announcement days, but also that this difference would be even higher if, ex post, the Fed adopts a policy of monetary easing.

3 Data

We work with tick-by-tick high frequency data that runs from January 1, 1994 to December 31, 2010. There are eight scheduled FOMC meetings in one year. This leaves us with 136 FOMC announcement days and 4,107 days with no pre-scheduled FOMC announcements. Out of the 136 announcement days, the target federal funds rate was increased in 30 instances, while it was decreased in 22 occasions. On the remaining 84 days, the target rate remained unchanged.

High-Frequency Currency Data: The high-frequency spot exchange rate data for Australia, Canada, Euro, Japan, New Zealand, Norway, Sweden, Switzerland, and the UK, all vis-à-vis the U.S. dollar, are from Olsen & Associates. We focus on these so called "G10" currencies, because they are the most heavily traded (Bank for International Settlements, 2015). The raw data consists 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.[9] For our benchmark results, we calculate returns by sampling data at 4pm Eastern Time (ET).

Spot and Forward Data: To calculate currency excess returns, we combine our high-frequency spot data with the daily data for spot exchange rates and one-month forward rates (versus the U.S. dollar) obtained from BBI and WM/Reuters (via Datastream). We denote spot and forward rates in logs by s_t and fw_t, respectively. The log excess return rx_{t+1} of purchasing a foreign currency in the forward market and then selling it in the spot market after one month is $rx_{t+1} = fw_t - s_{t+1}$. This excess return can also be stated as the log forward discount minus the change in the spot rate: $rx_{t+1} = fw_t - s_t - \Delta s_{t+1}$. 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 and domestic nominal risk-free rates over the maturity of the contract.[10] To calculate daily excess returns, we sample the spot rate at different points in time using the high-frequency data.

Volatilities: To obtain measures for intra-day realized volatility, we first calculate spot FX 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 made around, but not precisely at,

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

[10] The daily data from Datastream is sampled at 4pm London time. We verify that the daily data from WM/Reuters and our sampled high-frequency data are virtually identical.

215pm ET. We follow Fleming and Piazzesi (2005) and collect precise announcement times from the Bloomberg newswire, though with some abuse of terminology, we use 215pm and the announcement time interchangeably.

Monetary Policy Indicators: To construct our benchmark indicator for monetary policy shocks, we use the methodology proposed by Rogers, Scotti, and Wright (2015), which measures the change in five-year Treasury future prices from 15 minutes before the time of the FOMC announcement to 1 hour 45 minutes afterwards. A positive value for this indicator corresponds to an expansionary change in policy. Our reliance on longer maturity bonds to measure the effect of monetary shocks (as opposed to using federal funds futures as in Kuttner (2001) or Bernanke and Kuttner (2005)) is due to the well-known fact that over the past two decades FOMC announcements concerning the target federal funds rate have been largely anticipated by the market (Gürkaynak, Sack, and Swanson, 2007).

As an alternative indicator for monetary policy shocks, we use the composite measure suggested by Gürkaynak, Sack, and Swanson (2005) and Nakamura and Steinsson (2015). This measure is constructed by extracting the principal component of changes in federal funds futures and eurodollar futures for different horizons spanning one year in a 30-minute window around the FOMC announcement.

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), henceforth Treasury Implied Volatility or TIV (Choi, Mueller, and Vedolin, 2014). In our robustness analysis, we proxy monetary policy uncertainty with two alternative measures known as EPU and DiB FF. EPU is the economic policy uncertainty index of Baker, Bloom, and Davis (2015), whereas DiB FF is a cross-sectional mean standard deviation from forecasts of the federal funds rate available from Bloomberg.

Finally, as a proxy for market participants' appetite for risk, we use the VIX index of implied volatility in the stock market (Pan and Singleton, 2008; Adrian and Shin, 2010; Miranda-Agrippino and Rey, 2015).

4 Empirical Analysis

This section contains our main empirical results. We start our analysis by comparing the characteristics of returns on individual currencies on announcement and non-announcement days. We then focus on currency portfolios sorted on interest rates and test our model's predictions. A number of robustness checks confirm that (i) returns to a trading strategy that is short the U.S. dollar and long the other currencies are (on average) significantly larger on days with an FOMC policy announcement; (ii) there is a significant drift prior to the announcement; (iii) overall returns are higher when the Fed adopts an expansionary policy; and (iv) returns increase with the currency's interest rate differential vis-à-vis the U.S.

4.1 Individual Currency Returns & Volatilities

Table 1 presents average daily excess returns of the G10 currencies (in bps) on days with and without a scheduled FOMC announcement, sampled at three different times. Panel A samples returns at 4pm London time, which corresponds to the official WM/Reuters fixing time for currencies. The WM/Reuters daily closing rates — which are announced just after 4pm London time based on prices that take place in the one-minute window around 4pm (that is, from 15:59:30 to 16:00:30) — are widely used as benchmark exchange rates (similar to the LIBOR) for customer trades in the London and New York markets. Panel B samples returns at 215pm ET, which is the time when the FOMC announces its monetary policy decisions. Finally, Panel C of Table 1 samples returns at 4pm ET, which corresponds to the closing time of the stock market in New York.

[Insert Table 1 here.]

There are several noteworthy observations. First, when sampled at 4pm ET, daily returns are significantly larger on announcement days relative to non-announcement days. For example, the average daily return of the Australian dollar (AUD) on announcement days is 21.76bps, compared to 0.98bps on non-announcement days, amounting to a statistically significant difference of 20.78bps (with a t-statistic of 2.72). In fact, the table illustrates that consistent with our model's prediction in Proposition 1, differences in returns between announcement and non-announcement days are significant for all currencies except for the Japanese yen, the Swiss franc, and the Norwegian krona.

Second, since currency excess returns consist of an interest rate and an exchange rate component, it is natural to ask which of the two factors contributes the most to the observed returns. Our results indicate that most of the return is earned due to changes in the foreign exchange as opposed to the interest rate differential. Line "fx" in Panel C, which denotes how much of the daily return is earned as a consequence of changes in the foreign exchange, suggests that almost the entire return is attributable to the exchange rate change. This observation is consistent with our model's prediction that announcement day excess returns can materialize even when there are no changes in interest rates, an issue that we explore in further detail in the following subsections.

Third, we note that differences between announcement and non-announcement days are larger for currencies that have higher interest rate differentials vis-à-vis the U.S. For example, the difference between announcement and non-announcement day returns for the Australian and New Zealand dollars, two typical investment currencies, is about 20bps, which is statistically different from zero in both cases. In contrast, the Japanese yen and the Swiss franc, two typical funding currencies, have much smaller differences, neither of which are statistically different from zero. This finding is in line with our theoretical prediction in Proposition 2, according to which currencies with larger interest rate differentials should exhibit larger excess returns on announcement days.

Finally, we can explore how returns compare across different sampling times. Lucca and Moench (2015) report that most of the S&P500's return is earned in the 24-hour window right before the announcement at 215pm ET, an effect that they refer to as the "pre-announcement" drift. Foreign exchange returns, however, seem to follow a different pattern. In particular, as indicated in Panel B of

Table 1, when sampled at 215pm ET, the difference between announcement and non-announcement day returns is not statistically significant for any of the currencies. Similarly, if sampled at the London fixing time, none of the currencies — except for the Australian dollar and British pound — exhibit returns on announcement days that are statistically different from those on other days.[11] Taken together, these observations suggest that, different from the equity market, currencies exhibit excess returns that span the entire announcement day, consisting of a *pre-* as well as a *post-*announcement component. Viewed through the prism of our model, the pre-announcement component is a risk premium earned in compensation for monetary policy uncertainty, whereas the post-announcement component depends on the actual realization of the monetary policy adopted by the Fed.

We end this discussion by recalling that one prediction of our model is that exchange rate volatility plays a key role in determining currency excess returns (via impacting the financiers' risk-bearing capacity). Figure 1 plots the daily movement of average realized volatility of the G10 currencies' exchange rates on announcement and non-announcement days. The numbers in parentheses correspond to the t-statistic of a test of zero mean difference between realized variances in the one-hour window around 215pm ET.

[Insert Figure 1 here.]

As the figure indicates, realized volatility on announcement days before and after the announcement is low and statistically indistinguishable from the realized volatility at corresponding times on non-announcement days. However, around the time of the announcement, realized volatility spikes considerably for all currencies and is statistically different from the volatility sampled at the same time on non-announcement days.

4.2 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, in order 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 individual currencies with higher interest rate differential vis-à-vis the U.S. 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 many others). To this end, we allocate currencies into three portfolios based on their observed forward discounts $fw_t - s_t$, or, equivalently, their interest rate differentials at the end of each month t.[12] Portfolios are ranked in increasing interest rate order, with pf1 (pf3) denoting the portfolio consisting of the three currencies with the lowest (highest) interest rates. We calculate daily log excess returns of individual currencies

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[11] Note that the time difference between London and New York can range between 4 to 6 hours throughout the year, as a result of the adoption of daylight-saving time. Nevertheless, throughout the year, the London fixing time of 4pm is before the FOMC announcement time at 215pm ET.

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

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). Panel A of Table 2 presents the resulting summary statistics, with DOL denoting the portfolio that is short the U.S. dollar and long all other currencies.

[Insert Table 2 and Figure 2 here.]

Our 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 -0.35bps (with a t-statistic of -0.41), whereas the high interest rate portfolio, pf3, earns an average daily return of 2.15bps (with a t-statistic of 2.16). The DOL portfolio has a daily return of 0.73bps, which is statistically insignificant (with a t-statistic of 0.94). Panel A of Table 2 also indicates that corresponding annualized Sharpe ratios are large in absolute value for high interest rate currencies. In particular, while pf1 only generates an annualized Sharpe ratio of -0.1, pf3 has a Sharpe ratio of 0.53.

Next, we study whether high and low interest rate currency portfolios exhibit different excess returns on announcement days compared to non-announcement days. Panels B and C of Table 2 present the main results. The average daily return on the low interest rate portfolio is 5.71bps on announcement days compared to -0.55bps on non-announcement days. This 6.26bps difference is not statistically significant, with a t-statistic of 1.17. On the other hand, the average daily return of the high interest rate currency portfolio is 16.83bps on announcement days compared to 1.67bps on non-announcement days, a 15.17bps difference which is significantly different from zero (with a t-statistic of 2.43). We also note that in contrast to the unconditional average taken over the entire sample (as presented in panel A of Table 2), the DOL portfolio features a large and statistically significant return on announcement days — 12.45bps, with a t-statistic of 2.43 — whereas the return on non-announcement days is insignificant, with a t-statistic of 0.60. The difference of 12.10bps between the announcement and non-announcement days is highly statistically different from zero with a t-statistic of 2.34. Notably, the large increases in mean returns around announcement days is not accompanied by an equally large increase in realized risk, as measured by realized volatility, since annualized Sharpe ratios are significantly larger on announcement than non-announcement days.[13]

Our empirical results thus indicate that a sizable portion of the currency portfolios' average yearly returns is earned on FOMC announcement days. For instance, the average yearly return on the high interest rate portfolio is $252 \times 2.147 = 541$bps, of which almost 25% (or $8 \times 16.829 = 134$bps) is earned on the eight FOMC announcement days. To assess the economic significance of this result, we compare these numbers to those reported for the equity market. In terms of size, the 17bps earned on pf3 seem much smaller than the 50bps documented for the equity market (Lucca and Moench, 2015). However, the leverage investors can take in the FX market is substantially higher than in equity

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

markets. For example, while standard leverage ratios in the equity market are around 2 to 1, retail investors in the FX market can use a leverage of up to 100 to 1 (or trade on a 1% margin), meaning that for any USD 100 invested, one can take a USD 10,000 bet.[14] Therefore, a levered investor who starts with USD 100 at the beginning of the year and earns 17bps per announcement day has a portfolio that is worth USD 10,136 ($\approx 10,000 \times 1.0017^8$) at the end of the year, implying a return of 36% compared to an 8% return in the equity market.

To see whether the announcement day returns are mainly earned before or after the announcement, we next sample returns from 4pm the day before until 215pm on the day of the announcement (or the exact timing) and then from the time of the announcement until 4pm on that day. Figure 2 plots pre- and post-announcement returns together with returns on non-announcement days. As the plot suggests, most of the return is earned prior to the announcement, even though post-announcement returns are also positive. On average, around 75% of the daily return is earned before 215pm, with the remaining 25% earned in the 105 minutes until the closing time. In terms of statistical significance, we find that all pre-announcement returns except for $\mathrm{pf1}$ are statistically different from the non-announcement returns whereas post-announcement returns are not, suggesting that most of the returns are earned prior to the announcement.

4.3 Time-Series of Currency Portfolios

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 more detail.

4.3.1 Benchmark Results

As a first exercise, we regress the three currency portfolios' excess returns on a dummy which takes the value of one on announcement days and zero otherwise:

$$rx^i_{t+1} = \alpha_0 + \alpha_1 \times \text{Announcement Dummy}_t + \epsilon_{t+1}, \qquad i = 1, 2, 3, \text{DOL}. \tag{11}$$

In this regression, the intercept α_0 measures the corresponding portfolio's mean return on non-announcement days, while α_1 measures the spread between announcement and non-announcement days' mean returns. Our findings, reported in Panel A of Table 3, mirror those in Table 2, with positive coefficients for the announcement dummy for all portfolios. Furthermore, except for the low interest rate portfolio $\mathrm{pf1}$, the spread between announcement and non-announcement day returns is significant for all portfolios, with $\alpha_1 = 15.20$ (t-statistic of 2.47) for the high interest rate portfolio. The estimates for the intercept α_0 are not significant except for $\mathrm{pf3}$, implying that there is little return to be earned on non-announcement days. Similarly, for the DOL portfolio, the announcement dummy ($\alpha_1 = 12.12$) is statistically significant whereas the intercept is not.

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[14] For example, FXCM, which is the largest retail forex firm offers a 100 to 1 leverage ratio by default (http://www.fxcm.com/uk/support/faq/margin-requirements). Similarly, OANDA, another large platform for FX trading, offers a 1% margin on all exchange rates we study (http://fxtrade.oanda.co.uk/help/margin-rates).

One prediction of our theoretical model is that the difference between returns on announcement and non-announcement days should increase with the interest rate differential vis-à-vis the U.S. (see Proposition 2). Indeed, we find that the estimated coefficients increase from 6.27 for $\mathrm{pf1}$ to 15.19 for $\mathrm{pf3}$.

[Insert Table 3 here.]

Next, we turn to testing two other predictions of our model, namely, that (i) higher monetary policy uncertainty leads to larger currency excess returns around announcements (Proposition 1); and (ii) an ex post decrease (increase) in interest rates in the U.S. raises (lowers) other currencies' excess returns (Proposition 3).

To check whether higher monetary policy uncertainty indeed leads to higher returns, we regress currency excess returns on the implied volatility index TIV, which serves as a proxy for monetary policy uncertainty:

$$rx^i_{t+1} = \alpha_0 + \alpha_1 \times \text{Announcement Dummy}_t \times \mathrm{TIV}_t + \alpha_2 \times \mathrm{TIV}_t + \epsilon_{t+1}, \qquad i = 1, 2, 3, \mathrm{DOL}. \tag{12}$$

In this regression, we are mainly interested in coefficient α_1, which measures the additional return one can earn on announcement days relative to non-announcement days as TIV increases. The results are reported in Panel B of Table 3. We find that except for $\mathrm{pf1}$, all estimated coefficients for α_1 are statistically significant and carry the expected positive sign, indicating that higher uncertainty increases currency returns. Interestingly, monetary policy uncertainty does not seem to matter for currency returns outside of announcement days as manifested in the insignificant estimates for α_2.

Finally, we test for the relationship between currency excess returns and the resolution of monetary policy uncertainty following the announcement. Recall that according to Proposition 3, the difference between returns on announcement and non-announcement days should be larger when the target federal funds rate is decreased. To test for this prediction, we regress the currency returns on the indicator of monetary policy proposed by Rogers, Scotti, and Wright (2015) interacted with the announcement dummy. This monetary policy indicator, which henceforth we refer to as MPI, is defined as the change in five-year Treasury future prices from 15 minutes before the time of the FOMC announcement to 1 hour 45 minutes afterwards. Our rationale for relying on this indicator as opposed to the change in the federal funds rate announced by the FOMC is twofold. First, within our sample of 136 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. Second, given its overnight nature, changes in the federal funds rate is 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 by the MPI due to its long horizon nature.

Panel C of Table 3 reports the results. Estimated coefficients are positive and highly statistically significant for all portfolios with t-statistics ranging between 3.33 and 3.99, thus implying that currency excess returns are higher when the Fed adopts a policy of monetary easing, an observation that is consistent with our theoretical results.[15]

4.3.2 Alternative Measures

We now present additional results that indicate that the effects identified above are not driven by the specific choice of how market participants' uncertainty about monetary policy or how the realization of monetary policy shocks is measured.

In Table 4, we summarize estimated coefficients from regressing currency portfolio excess returns on two alternative proxies for monetary policy uncertainty, namely, the economic policy uncertainty (EPU) index of Baker, Bloom, and Davis (2015) and DiB FF, which is a cross-sectional standard deviation from forecasts of the federal funds rate available from Bloomberg. As the table suggests, the estimated coefficient on the interaction term (that is, α_1 in equation (12)) are similar to our benchmark regressions: except for $\mathrm{pf1}$, all estimated coefficients are positive and significant.

[Insert Table 4 here.]

To test the robustness of our results to the choice of indicator for monetary policy shocks, we follow Gürkaynak, Sack, and Swanson (2005) and Nakamura and Steinsson (2015) and regress excess returns on a composite measure of changes in interest rates at different maturities. This composite measure is constructed by extracting the first principal component of changes in federal funds and eurodollar futures for different horizons spanning one year in a 30-minute window around the FOMC announcement. The corresponding results, reported in Table 4, confirm that the excess returns of all currency portfolios increase with the realization of expansionary monetary policy shocks.

Yet another prediction of our model maintains that excess returns should increase in market volatility in order to compensate the financiers accordingly. To test for this prediction, we regress excess returns on realized exchange rate volatility sampled from the high frequency data at 215pm (as in equation (12)). The estimated coefficients, also presented in Table 4, are all positive and highly significant, in line with the model's prediction. Similarly, we also regress each portfolio's excess returns on the VIX index of implied volatility of S&P 500 index options, which serves as a proxy for market participants' appetite for risk (Pan and Singleton, 2008; Adrian and Shin, 2010). As expected, the corresponding coefficients are all positive and significant, except for the low interest rate portfolio $\mathrm{pf1}$.

Overall, we find strong empirical evidence for our model's main predictions that (i) higher monetary policy uncertainty leads to higher excess returns on currency portfolios; and (ii) an expansionary monetary policy increases these returns even further.

4.4 Announcements by Other Central Banks

It is natural to ask whether announcements by other central banks have similar effects on currency returns. To this end, we collect announcement dates for the major currencies we study either from

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[15] Recall that a positive value for the MPI corresponds to an expansionary change in policy.

Bloomberg (if available) or from the webpages of the respective central banks: Australia, England, Japan, New Zealand, and Switzerland.[16]

As a first exercise, we re-base all currency rates into the local currency, 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 re-run the same exercise as for the FOMC announcement dates. We do not find any significant effects for other central bank announcements except for Japan, a typical funding currency.[17] In what follows, we first discuss Japan's monetary policy in more detail and then present the results.

The Bank of Japan (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 members produce a guideline for money market operations in inter-meeting periods, which 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 U.S.). This is the base rate which is charged when banks that are part of the system provide one another with loans with a short maturity, usually a maturity of one-day (overnight). The announcement of decisions are released right after the meeting and the minutes themselves are released about a month after each meeting. We note that announcements not only include interest rate decisions, but also the BoJ's collective outlook on the economy as well as guidance about future monetary policy decisions.

The uncollateralized call rate was lowered to virtually zero in February/March 1999, and with the exception of a brief interest rate increase in fall 2000, the rate has remained at the zero lower bound since then. So why would monetary policy announcements affect asset prices? Note that in addition to setting the interest rate, quantitative easing in Japan entails two other measures: (i) setting the target (reserves) of commercial banks at the BoJ in excess of required reserves; and (ii) setting the size of outright purchases of long-term government bonds, private equity, and debt, such as asset-backed securities.[18]

Monetary Policy Meeting dates are available from the Bank of Japan webpage since 1998. Spring 1998 coincides with the year 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 differential. The results are presented in Table 5.

[Insert Table 5 here.]

The findings are strikingly similar to the ones for the Federal Reserve. On days when the BoJ makes an announcement, the average daily return on the low interest rate portfolio is 16.94bps, compared to -0.85bps on non-announcement days. This 17.79bps difference is highly statistically

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[16] Most countries have either a very short history or a small number of pre-scheduled announcements, making any meaningful statistical analysis impossible. For example, Canada only started a fixed announcement schedule from 2001 onwards, Norway only met once per year until 2007, etc.

[17] In contrast, Brusa, Savor, and Wilson (2015) document that except for the Fed, there is no announcement effect on global stock market indices from other central banks and that the Fed exerts an unique impact on global equity prices.

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

significant, with a t-statistic of 2.78. For the high interest rate currency portfolio, the average return is 20.52bps on announcement days compared to 2.50bps on non-announcement days; a 18.02bps difference which is significantly different from zero (t-statistic of 2.64). Annualized Sharpe ratios are large and economically significant, ranging from 0.77 for $\mathrm{pf1}$ to 0.88 for $\mathrm{pf3}$.

Similar to the results for the U.S., a sizable portion of the portfolios' average yearly returns is earned on the BoJ announcement days. For instance, the average yearly return on $\mathrm{pf3}$ is $3.19 \times 252 = 803$bps of which almost 40% (or $15 \times 20.52 = 308$bps) are earned on the 15 announcement days. For the portfolio which is long all currencies and short the Japanese Yen (reported in the last column in Table 5), announcement returns contribute to 80% of the annualized premium (18.16bps$\times 15/1.41$bps $\times$ 252).

As a final remark, we note that since Japanese yen is one of the most prominent funding currencies, the similarity between the results for the BoJ and the FOMC should not be considered surprising. This similarity is also in line with our model's predictions, according to which the difference between returns on announcement and non-announcement days increases in the interest rate differential between the funding and investment currencies.

4.5 Robustness

We conclude this section by running several robustness checks. First, we redo the analysis for winsorized data to ensure that our results are not driven by outliers in the sample. Second, to overcome concerns about the sample size, we compute small sample standard errors through a bootstrap exercise. In a second bootstrap exercise, we sample randomly from the distribution of non-announcement returns to test whether we can generate returns similar in size to those observed on announcement dates. Finally, we check whether other macroeconomic announcements result in similarly large returns as the ones we documented for FOMC announcements.

4.5.1 Winsorized Data

One may suspect that our results are determined by a few outliers, as some announcements are more anticipated than others and it is well-known that currency returns occasionally experience large crashes. To test for the sensitivity of our results to such outliers, we winsorize the sample by discarding the top and bottom percentiles of the data. The results are reported in Table 6. We find that there is virtually no distinction between the means and standard deviations of winsorized and non-winsorized returns (reported in Table 2) across interest rate sorted portfolios, thus indicating that our results are not driven by a few outliers.

[Insert Table 6 here.]

4.5.2 Bootstrapped Standard Errors and Random Sampling

Bootstrapped standard errors: A natural concern for the results reported in Table 3 is that, due to the small number of observations, 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 of the point estimates of the dummy variable regression. In particular, we draw with replacement from the observed distribution, run regression (11), and store the estimated coefficients for each portfolio. The resulting empirical distributions are plotted in Figure 4. We note that the mean is very similar to the estimated coefficients for $\hat{\alpha}_1$ reported in Table 3. Moreover, standard errors are also similar to those reported for the regression.

[Insert Figure 4 here.]

Random Sampling from non-FOMC Distribution: In another bootstrap exercise, we draw with replacement a time-series with the length equal to the number of announcement days (136) from the distribution of non-announcement day returns. We present the resulting announcement and non-announcement day returns for the G10 currencies (Panel A) and the currency portfolios (Panel B) in Table 7. In addition, we also include the 95 percentile of the bootstrap distribution and the corresponding probabilities of observing a mean greater than the mean on announcement days by drawing from the non-announcement day distribution. In line with the asymptotic results, the mean announcement return sampled at 4pm ET and observed in the data is much higher than the 95 percentile of the bootstrap distribution for all currencies except for JPY, CHF, and NOK. Correspondingly, the probabilities of observing a higher mean when drawing from the non-announcement day data are often negligibly small.

4.5.3 Transaction Costs

To adjust for transaction costs, we rerun our main regressions using net returns (after deducting the bid-ask spread). The net return of a currency that enters the portfolio at month t and exits the following month 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 8.

[Insert Table 8 here.]

While returns are lower than those reported in Table 2, they are still significant as indicated by the t-statistics (except for pf1). We conclude that shorting the U.S. dollar is profitable even when accounting for transaction costs.

4.5.4 Other Macroeconomic Announcements

Are other macroeconomic announcements also able to generate similarly large returns as those earned around FOMC announcements? To answer this question, we consider three major U.S. macroeconomic news releases: total non-farm payroll employment, the Producer Price Index, and the Consumer Price Index, all published by the Bureau of Labor Statistics (BLS).[19] We build announcement day dummy variables and check for larger conditional returns by means of the following regression:

$$rx_{t+1}^{i} \quad = \quad \alpha_0 + \alpha_1 \times \text{Announcement Dummy}_t^{\text{E, CPI, PPI}} + \epsilon_{t+1},$$

where rx_t^i is the currency return and $\text{Announcement Dummy}_t^{\text{E, CPI, PPI}}$ is a dummy variable that takes the value of one on days when non-farm payroll employment (E), consumer price index (CPI), or the producer price index (PPI) are announced. Results, reported in Table 9, show that none of these announcements produce significant results, thus indicating the unique role of monetary policy announcements in generating large excess returns on currency portfolios.

[Insert Table 9 here.]

5 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 non-announcement days. This difference is increasing in the forward discount of the currency and becomes significantly larger when the Fed adopts a policy of monetary easing. Moreover, using different proxies of 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. In particular, exchange rates 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 a compensation to financiers who bear this extra risk. We also show that, consistent with our empirical observations, these risk premia are increasing in the foreign currency's interest rate differential. Currency excess returns on announcement days materialize independent of whether the federal funds rate is, ex post, changed or not. However, our model predicts that, in line with our empirical observations, the actual realization of monetary policy shock also impacts currency excess returns with an expansionary (contractionary) policy resulting in higher (lower) returns.

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[19] We chose these three macroeconomic variables, as they are likely to be linked to monetary policy. We also checked for other important macroeconomic news announcements such as initial claims for unemployment insurance, the Institute for Supply Management's manufacturing index, and housing starts but did not find any significant results.

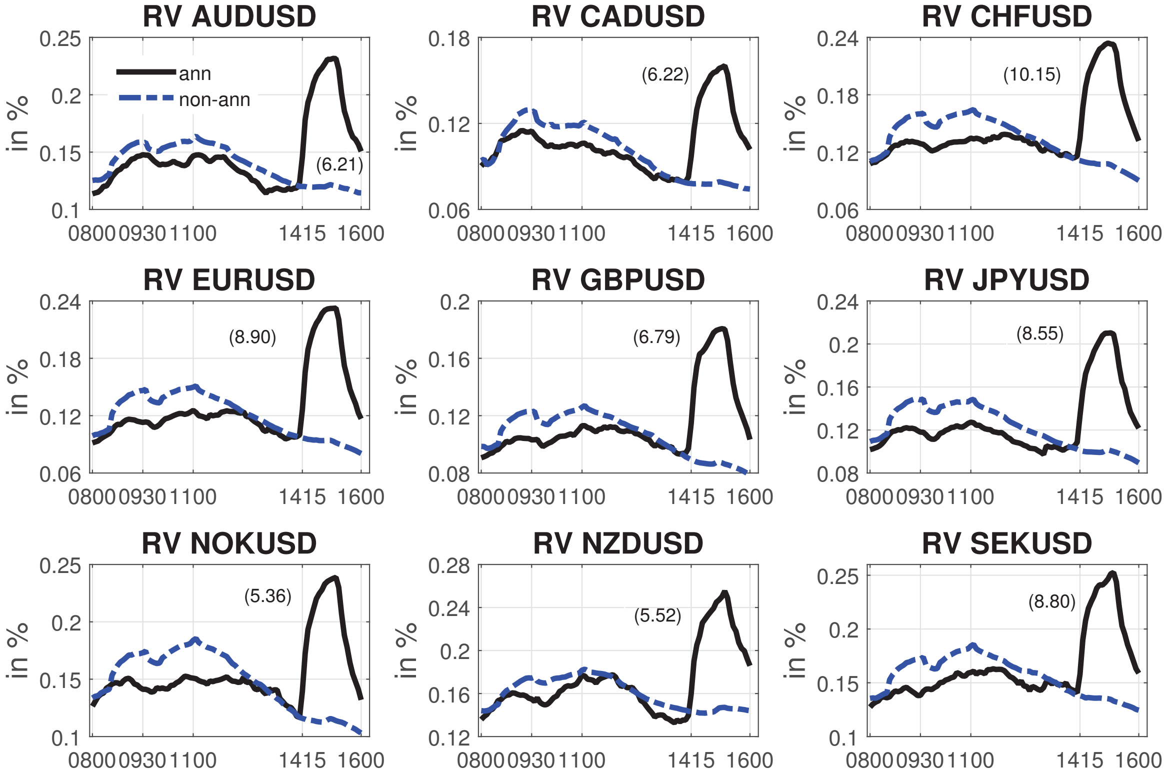

Figure 1. **Foreign Exchange Realized Volatility**

This figure plots average realized exchange rate volatility on FOMC announcement days (ann) and all other days (non-ann). Realized volatilities are calculated from data sampled at five-minute frequency over a one-hour window and are expressed in percent and annualized. The numbers in parentheses are t-statistics of a test of equal means between announcement and non-announcement days realized volatilities, calculated based on a one-hour window around the time of the announcement. The data runs from January 1, 1994 to December 31, 2010.

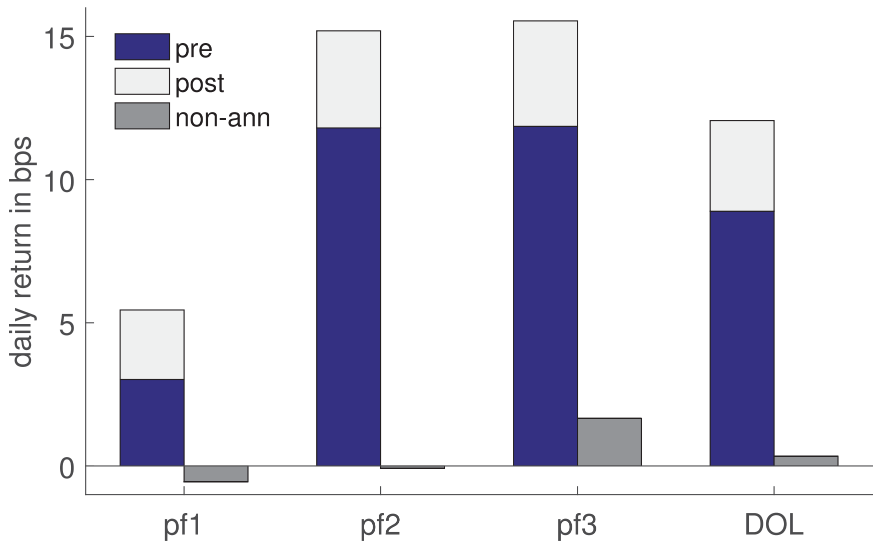

Figure 2. **Currency excess returns on FOMC announcement and non-announcement days**

This figure plots average daily currency returns (sampled from 4pm to 4pm ET) on announcement and non-announcement days for portfolios sorted on their interest rate differentials. Announcement returns are split into pre-announcement (from 4pm to 215pm ET) and post-announcement returns (from 215pm to 4pm ET). Pf1 and pf3 are, respectively, the portfolios with the lowest and highest interest rate differentials. DOL denotes the average return of the three currency portfolios. The sample runs from January 1, 1994 to December 31, 2010.

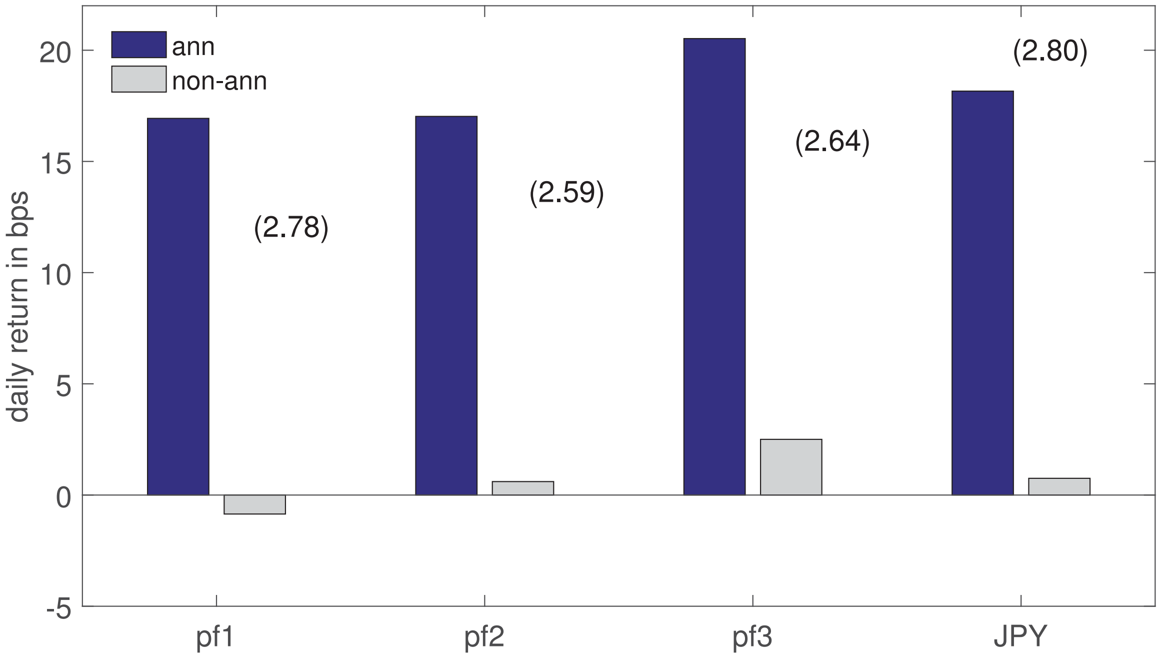

Figure 3. **Currency excess returns on days with and without an announcement by the Bank of Japan**

This figure plots average daily currency returns (in basis points) for portfolios sorted on their interest rate differential, with pf1 denoting the portfolio with the lowest interest rate differential. All currencies are quoted vis-à-vis the Japanese yen. JPY denotes the average return of the three currency portfolios. The numbers in parentheses are t-statistics of a test of equal means between returns on BoJ and non-BoJ announcement days. Data used is daily and runs from January 1, 1998 to December 31, 2010.

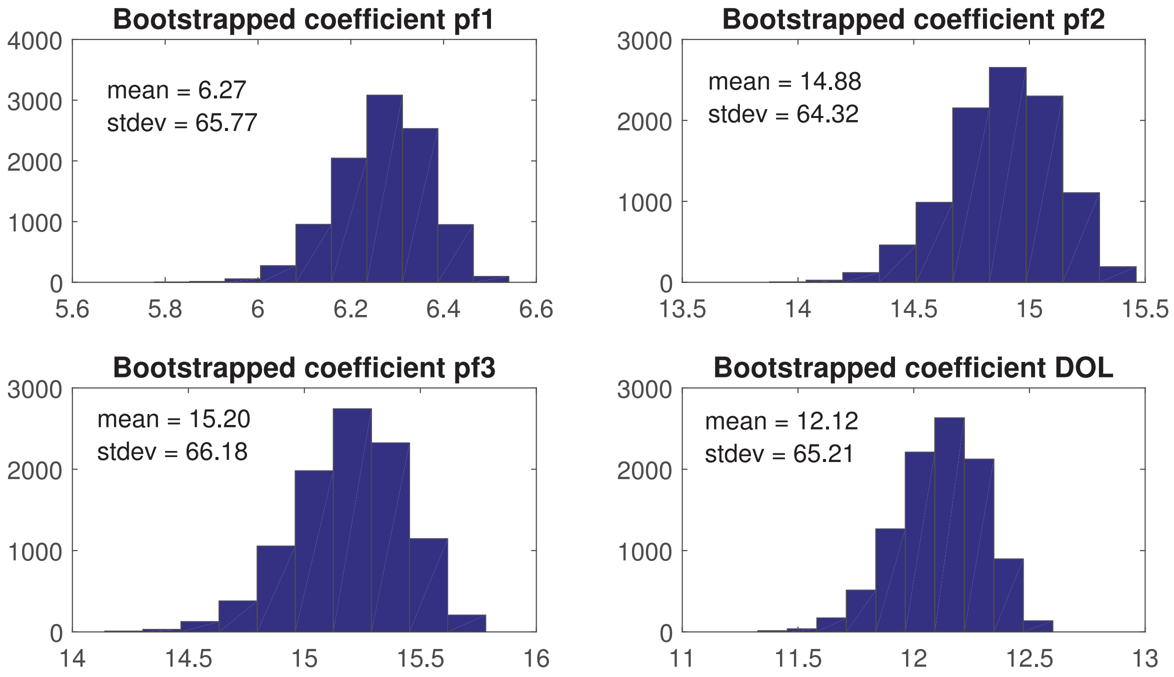

Figure 4. **Empirical distribution of bootstrapped regression coefficients**

This figure plots the empirical distribution for regression coefficients $\hat{\alpha}_1$ in regression (11) for the interest rate sorted portfolios $\mathrm{pf1}$, $\mathrm{pf2}$, and $\mathrm{pf3}$, as well as the DOL portfolio. The sample period runs from January 1, 1994 to December 31, 2010.

Table 1. Summary Statistics of Individual Currency Returns

This table reports summary statistics of individual currency returns (xrt) on FOMC announcement and non-announcement days. "fx" represents how much of the return is earned from the change in the foreign exchange. t-stats are for tests of a difference in mean between announcement and non-announcement returns. The sample covers January 1, 1994 to December 31, 2010. All numbers are expressed in daily returns (in bps). Panel A samples returns at 4pm London (London fixing time), Panel B samples returns from 215pm to 215pm (the announcement time), and finally Panel C samples daily returns from 4pm to 4pm ET (closing time).

		AUD	CAD	CHF	EUR	GBP	JPY	NOK	NZD	SEK
		`Panel A: Returns sampled at 4pm London`								
ann	xrt	16.978	3.340	6.488	4.381	11.590	6.360	7.295	15.390	8.960
non-ann	xrt	1.139	0.540	0.010	0.006	0.144	-0.860	0.710	1.385	0.255
diff	t-stat	(1.96)	(0.54)	(0.80)	(0.57)	(1.80)	(0.94)	(0.72)	(1.44)	(1.01)
		`Panel B: Returns sampled at 215pm ET`								
ann	xrt	11.295	-1.382	7.906	4.392	8.398	5.137	9.401	5.449	9.207
non-ann	xrt	1.326	0.694	-0.021	0.017	0.260	-0.811	0.650	1.712	0.254
diff	t-stat	(1.13)	(-0.39)	(0.98)	(0.56)	(1.24)	(0.76)	(0.92)	(0.36)	(0.97)
		`Panel C: Returns sampled at 4pm ET`								
ann	xrt	21.764	19.522	6.374	9.983	15.220	-1.592	7.884	20.274	11.903
	fx	21.115	18.883	8.027	9.738	14.068	-0.383	8.021	20.230	11.002
non-ann	xrt	0.982	-0.015	0.029	-0.169	0.052	-0.577	0.700	1.232	0.156
	fx	0.276	0.022	0.901	0.087	-0.355	0.801	0.381	0.157	0.145
diff	t-stat	(2.72)	(3.52)	(0.88)	(1.66)	(2.94)	(-0.16)	(1.06)	(2.50)	(1.79)

Table 2. Summary Statistics of Currency Portfolio Returns

This table reports summary statistics of currency returns on announcement (Panel B) and non-announcement days (Panel C). Panel A reports summary statistics for all days. Portfolios are sorted according to their interest rate differentials, with pf1 (pf3) denoting the portfolio with the lowest (highest) interest rate differential. DOL denotes the average return of the three portfolios. Announcement days are when the FOMC releases its interest rate decisions. The row labeled "diff" indicates the difference in average returns between announcement and non-announcement days, with the corresponding t-statistic presented in parentheses below. The sample covers January 1, 1994 to December 31, 2010. All numbers are expressed in daily returns (in bps) except for Sharpe ratios, which are annualized taking into account the annual frequency of FOMC announcements $(8/252)$. Thus FOMC SR $=$ [daily mean return FOMC/daily std returns FOMC]$\sqrt{8}$, and NON FOMC SR $=$ [daily mean return NON FOMC/daily std returns NON FOMC]$\sqrt{244}$.

	pf1	pf2	pf3	DOL
		`Panel A: all days`		
mean	-0.353	0.392	2.147	0.729
t-stat	(-0.41)	(0.47)	(2.16)	(0.94)
stdev	55.541	54.067	64.835	50.685
skew	0.342	0.026	-0.328	0.060
kurt	5.755	7.115	9.322	5.870
SR	-0.101	0.115	0.526	0.228
		`Panel B: announcement days`		
mean	5.712	14.798	16.829	12.446
t-stat	(1.09)	(2.80)	(2.73)	(2.43)
stdev	61.373	61.607	71.818	59.659
skew	1.696	1.756	1.876	2.135
kurt	7.963	10.350	9.509	10.660
SR	0.263	0.679	0.663	0.590
		`Panel C: non-announcement days`		
mean	-0.553	-0.085	1.661	0.341
t-stat	(-0.88)	(-0.14)	(2.26)	(0.60)
stdev	55.335	53.742	64.543	50.322
skew	0.279	-0.068	-0.434	-0.063
kurt	5.609	6.832	9.227	5.427
SR	-0.089	0.000	0.435	0.151
diff	6.265	14.883	15.168	12.105
t-stat	(1.17)	(2.78)	(2.43)	(2.34)

Table 3. Baseline Regression Results

This table reports estimated coefficients from running regressions from foreign exchange excess return portfolios on a dummy that takes the value of one on days when the FOMC makes an announcement and zero otherwise (Panel A). In Panel B, we regress portfolio returns on a proxy of monetary uncertainty (TIV) and its interaction with the announcement dummy. Panel C regresses portfolio returns on our monetary policy indicator (MPI) interacted with the announcement dummy. Data runs from January 1, 1994 to December 31, 2010. Numbers in parentheses denote Newey and West (1987) t-statistics.

	pf1	pf2	pf3	DOL
`Panel A: ann and non-ann returns`				
constant	-0.558	-0.088	1.639	0.331
t-stat	(-0.64)	(-0.10)	(1.71)	(0.42)
ann dummy	6.270	14.886	15.189	12.115
t-stat	(1.18)	(2.78)	(2.47)	(2.36)
R^2	0.02%	0.21%	0.15%	0.15%
`Panel B: monetary policy uncertainty`				
constant	-3.938	-1.058	-0.833	-1.943
t-stat	(-1.04)	(-0.22)	(-0.15)	(-0.45)
TIV × ann dummy	1.709	3.418	3.806	2.978
t-stat	(1.36)	(2.53)	(2.50)	(2.27)
TIV	0.861	0.228	0.590	0.560
t-stat	(0.84)	(0.17)	(0.38)	(0.46)
R^2 (in %)	0.07	0.36	0.31	0.32
`Panel C: monetary policy indicator`				
constant	-0.512	0.300	1.942	0.577
t-stat	(-0.59)	(0.36)	(2.05)	(0.74)
MPI × ann dummy	4.875	5.620	5.427	5.307
t-stat	(3.99)	(3.60)	(3.33)	(3.76)
R^2 (in %)	0.75	1.06	0.68	1.08

Table 4. Regression Analysis Additional Proxies

This table reports estimated coefficients from running regressions of currency portfolios on various explanatory variables as given in equation (12) for the monetary policy uncertainty proxies (EPU, DiB FF) and global risk appetite (RV ann and VIX). “pf1” (“pf3”) is the portfolio with the lowest (highest) interest rate differential, and DOL is the average of the three portfolios. EPU is economic policy uncertainty, DiB FF is disagreement about the Fed Funds Rate, RV ann is realized exchange rate volatility measured over a two-hour window around the time of an FOMC announcement, and VIX is S&P500 implied volatility. MPI (GSS) refers to the indicator for monetary policy shock of Gürkaynak, Sack, and Swanson (2005). For brevity, we only report estimated coefficient for the interaction term. Data runs from January 1, 1994 to December 31, 2010. Newey and West (1987) t-statistics are in parentheses.

	pf1					pf2				
EPU × ann dummy	0.058					0.115				
	(1.36)					(2.54)				
DiB FF × ann dummy		1.812					4.297			
		(1.07)					(2.47)			
MPI (GSS) × ann dummy			4.195					3.019		
			(3.24)					(2.14)		
RV ann × ann dummy				0.651					1.450	
				(1.47)					(2.92)	
VIX × ann dummy					0.560					1.018
					(1.61)					(2.72)
constant	-0.361	-0.643	-0.701	-7.525	-1.916	0.457	3.899	0.094	1.842	6.516
	(-0.23)	(-0.17)	(-0.78)	(-2.49)	(-0.70)	(0.23)	(1.09)	(0.11)	(0.50)	(1.76)
Adj. R^2 (in %)	0.05	0.01	0.53	0.63	0.13	0.28	0.16	0.28	0.82	0.74

	pf3					DOL				
EPU × ann dummy	0.116					0.097				
	(2.17)					(2.17)				
DiB FF × ann dummy		4.194					3.434			
		(1.99)					(2.02)			
MPI (GSS) × ann dummy			3.932					3.715		
			(2.20)					(2.65)		
RV ann × ann dummy				1.838					1.313	
				(3.48)					(2.83)	
VIX × ann dummy					1.174					0.918
					(2.56)					(2.41)
constant	0.934	1.629	1.840	8.782	11.322	0.343	1.628	0.411	1.033	5.307
	(0.47)	(0.37)	(1.81)	(2.11)	(2.89)	(0.21)	(0.47)	(0.49)	(0.33)	(1.69)
Adj. R^2 (in %)	0.22	0.09	0.33	0.94	0.84	0.23	0.11	0.50	0.80	0.63

Table 5. Currency Returns Summary Statistics on announcement days by the Bank of Japan

This table reports summary statistics of currency returns on announcement (Panel B) and non-announcement days (Panel C). Panel A reports summary statistics for all days. Portfolios are sorted according to their interest rate differential. Pf1 (pf3) has the lowest (highest) interest rate differential. JPY denotes the average return of the three portfolios. Announcement days are when the Bank of Japan (BoJ) releases its interest rate decisions. The row denoted by "diff" indicates the difference in average returns between announcement and non-announcement returns, and the corresponding t-statistic is presented in parentheses below. The sample covers February 1, 1998 to December 31, 2010. All numbers are expressed in daily returns (in bps) except for Sharpe ratios, which are annualized taking into account the annual frequency of BoJ announcements $(15/252)$. Thus BoJ SR $=$ [daily mean return FOMC/daily std returns FOMC]$\sqrt{15}$, and NON BoJ SR $=$ [daily mean return NON BoJ/daily std returns NON BoJ]$\sqrt{237}$.

	pf1	pf2	pf3	JPY
		`Panel A: all days`		
mean	-0.188	1.247	3.188	1.415
t-stat	(-0.16)	(1.01)	(2.25)	(1.18)
stdev	75.559	80.155	92.438	78.317
skew	-0.596	-0.767	-0.630	-0.731
kurt	8.322	10.673	12.340	10.941
SR	-0.040	0.247	0.547	0.287
		`Panel B: announcement days`		
mean	16.936	17.024	20.524	18.161
t-stat	(2.69)	(2.74)	(3.07)	(2.98)
stdev	85.148	84.008	90.393	82.489
skew	0.748	0.067	0.433	0.377
kurt	6.780	4.601	5.637	5.548
SR	0.770	0.785	0.879	0.853
		`Panel C: non-announcement days`		
mean	-0.853	0.606	2.504	0.752
t-stat	(-1.00)	(0.67)	(2.38)	(0.85)
stdev	75.226	79.965	92.504	78.152
skew	-0.655	-0.806	-0.669	-0.778
kurt	8.446	10.980	12.586	11.211
SR	-0.176	0.117	0.419	0.149
diff	17.789	16.419	18.019	17.409
t-stat	(2.78)	(2.59)	(2.64)	(2.80)

Table 6. Currency Return Summary Statistics for Winsorized Data

This table reports summary statistics of currency returns on announcement and non-announcement days for a winsorized sample where we remove outliers at the bottom and top 1%. Announcement days are when the FOMC releases its interest rate decisions. pf1 is the portfolio with the lowest interest rate differential, while pf3 has the highest interest rate differential. DOL is a portfolio which is short the USD and long the rest of the currencies. The sample covers January 1, 1994 to December 31, 2010.

	pf1		pf2		pf3		DOL	
	ann	non-ann	ann	non-ann	ann	non-ann	ann	non-ann
mean	0.463	-0.467	12.189	-0.067	11.856	1.695	8.169	0.387
t-stat	(0.12)	(-0.52)	(2.49)	(-0.08)	(1.93)	(1.62)	(1.80)	(0.47)
stdev	46.445	57.310	56.714	55.468	71.180	66.308	52.418	52.448
skew	1.755	0.429	3.469	-0.021	3.964	-0.586	4.153	0.106
kurt	11.195	7.096	26.462	7.333	31.889	13.308	33.524	7.697
N	134	4026	134	4026	134	4026	134	4026

Table 7. Monte Carlo Analysis

This table reports summary statistics of individual currency returns (xrt) on announcement and non-announcement days as in Tables 1 and 2. t-stats are for tests of a difference in mean between announcement and non-announcement returns. "MC 95%" denotes the 95 percentile from a bootstrap distribution obtained from sampling on non-announcement days. The p-values denote the probability of observing a mean greater than the corresponding value on announcement days by drawing from the sample of non-announcement days. The sample covers January 1, 1994 to December 31, 2010. All numbers are expressed in daily returns (in bps). Panel A presents the results for the individual currencies whereas Panel B presents the results for the G10 currency portfolios and the DOL portfolio.

Panel A: Individual currencies

		AUD	CAD	CHF	EUR	GBP	JPY	NOK	NZD	SEK
t-stat	4pm London	(1.96)	(0.54)	(0.80)	(0.57)	(1.80)	(0.94)	(0.72)	(1.44)	(1.01)
	215pm New York	(1.13)	(-0.39)	(0.98)	(0.56)	(1.24)	(0.76)	(0.92)	(0.36)	(0.97)
	4pm New York	(2.72)	(3.52)	(0.88)	(1.66)	(2.94)	(-0.16)	(1.06)	(2.50)	(1.79)
ann	4pm London	16.98	3.34	6.49	4.38	11.59	6.36	7.30	15.39	8.96
	215pm New York	11.29	-1.38	7.91	4.39	8.40	5.14	9.40	5.45	9.21
	4pm New York	21.76	19.52	6.37	9.98	15.22	-1.59	7.88	20.27	11.90
non-ann	4pm London	1.14	0.54	0.01	0.01	0.14	-0.86	0.71	1.39	0.26
	215pm New York	1.33	0.69	-0.02	0.02	0.26	-0.81	0.65	1.71	0.25
	4pm New York	0.98	-0.01	0.03	-0.17	0.05	-0.58	0.70	1.23	0.16
MC 95%	4pm London	12.19	8.15	9.66	8.90	8.19	9.32	10.85	12.66	10.47
	215pm New York	12.59	8.18	9.93	9.14	8.44	9.64	11.11	12.82	10.93
	4pm New York	12.30	7.17	9.84	9.03	8.07	9.73	11.19	12.47	10.85
p-values	4pm London	1.0%	26.9%	13.4%	20.6%	1.0%	12.0%	14.2%	2.1%	7.9%
	215pm New York	7.3%	67.4%	9.4%	21.5%	5.1%	17.2%	8.4%	29.0%	8.5%
	4pm New York	0.1%	0.0%	13.9%	3.4%	0.1%	54.6%	12.6%	0.3%	3.4%

Panel B: G10 portfolios

		pf1	pf2	pf3	DOL
t-stat	4pm London	(1.02)	(0.83)	(1.67)	(1.29)
	215pm New York	(0.90)	(0.49)	(1.04)	(0.88)
	4pm New York	(1.17)	(2.78)	(2.43)	(2.34)
ann	4pm London	6.621	5.349	15.192	9.097
	215pm New York	6.036	3.482	10.669	6.776
	4pm New York	5.712	14.798	16.829	12.481
non-ann	4pm London	-0.589	0.164	1.768	0.488
	215pm New York	-0.522	0.266	1.858	0.575
	4pm New York	-0.547	-0.084	1.672	0.388
MC 95%	4pm London	7.091	7.738	10.767	7.515
	215pm New York	7.291	7.941	10.889	7.704
	4pm New York	7.278	7.448	10.737	7.476
	4pm London	6.1%	12.9%	0.7%	2.3%
	215pm New York	8.4%	24.5%	5.5%	7.7%
	4pm New York	9.1%	0.0%	0.3%	0.2%

Table 8. Currency Portfolio Return Summary Statistics Net of Transaction Costs

This table reports summary statistics for currency returns earned on FOMC announcement days net of transaction costs. Announcement days are when the FOMC releases its interest rate decisions. The sample covers January 1, 1994 to December 31, 2010. All numbers are expressed in daily returns (in bps) except for Sharpe ratios, which are annualized taking into account the annual frequency of FOMC announcements $(8/252)$.

	pf1	pf2	pf3	DOL
mean	2.782	9.977	10.506	7.755
t-stat	(0.56)	(1.95)	(2.06)	(1.64)
stdev	58.065	59.659	59.211	55.230
skew	1.531	1.796	1.804	2.111
kurt	7.215	10.388	9.135	10.485
SR	0.135	0.473	0.501	0.397

Table 9. Currency Return Summary Statistics Macro Announcements

This table reports summary statistics of currency returns on announcement and non-announcement days for CPI, PPI and non-farm payroll employment. Portfolios are sorted according to their interest rate differential. Pf1 (pf3) has the lowest (highest) interest rate differential. DOL denotes the average return of the three portfolios. Diff mean indicates the difference in average returns between announcement and non-announcement returns, and the corresponding t-statistic is presented in parentheses below. The sample covers January 1, 1994 to December 31, 2010. All numbers are expressed in daily returns (in bps).

	pf1	pf2	pf3	DOL
Consumer Price Index				
ann	0.079	0.839	3.578	1.499
t-stat	(0.02)	(0.21)	(0.68)	(0.37)
stdev	61.457	57.384	74.322	57.486
non-ann	-0.374	0.370	2.076	0.691
diff in mean	0.452	0.469	1.502	0.808
t-stat	(0.10)	(0.11)	(0.28)	(0.20)
Purchasing Power Index				
ann	1.624	3.758	5.872	3.751
t-stat	(0.40)	(1.05)	(1.41)	(1.09)
stdev	58.541	51.229	59.605	49.347
non-ann	-0.452	0.222	1.959	0.576
diff in mean	2.076	3.536	3.913	3.175
t-stat	(0.50)	(0.96)	(0.91)	(0.90)
Non-Farm Payroll Employment				
ann	-7.244	3.372	6.728	0.952
t-stat	(-1.64)	(0.79)	(1.47)	(0.24)
stdev	62.569	60.506	64.805	57.006
non-ann	-0.012	0.245	1.921	0.718
diff in mean	-7.232	3.127	4.807	0.234
t-stat	(-1.60)	(0.72)	(1.02)	(0.06)

A Value-at-Risk Constraints

In this appendix, we show that our main theoretical results remain unchanged if financiers are subject to a value-at-risk constraint as opposed to the limited commitment constraint of Gabaix and Maggiori (2015), thus illustrating that our model's key insights are not sensitive to the specific nature of the constraint assumed in Section 2. To make the analysis tractable, we assume that financiers are only uncertain about monetary policy in the U.S. and face no fundamental uncertainty. In particular, we assume that $f_1 = f_0 = f$ and $d_1 = d_0 = d$.

Consider the model presented in Section 2 and suppose that instead of the limited commitment constraint in (2), each financier is subject to a value-at-risk constraint in the spirit of Adrian and Shin (2014), according to which the likelihood that her wealth at $t = 1$ falls below some negative threshold ϵ cannot exceed some $\alpha < 1$.[20] As a result, the representative financier faces the following problem:

$$\begin{aligned} \max_{Q} \quad & \mathbb{E}[V] \\ \text{s.t.} \quad & \mathbb{P}(V \leq \epsilon) \leq \alpha, \end{aligned} \tag{13}$$

where $V = (R^* e_1/e_0 - R)\, Q$. Given that the value-at-risk constraint has to bind at the optimal solution, the representative financier's position Q satisfies

$$\mathbb{P}\left(\frac{R^* Q(f - RQ)}{f + Q} - RQ \leq \epsilon \right) = \alpha,$$

where we are using the fact that exchange rates satisfy the market clearing conditions (3) and (4). As a result,

$$\mathbb{P}\left(R \geq \frac{R^* f - \epsilon(Q + f)/Q}{f + Q(R^* + 1)} \right) = \alpha,$$

which implies that, when $\epsilon \to 0$,

$$Q = \frac{f}{R^* + 1} \left(\frac{R^*}{\mathbb{E}[R] + \sigma_R F^{-1}(1 - \alpha)} - 1 \right), \tag{14}$$

where F denotes the cumulative distribution function of the interest rate R when re-centered around zero and normalized by its standard deviation. Combining the above with the market clearing conditions (3) and (4) implies that equilibrium exchange rates are given by

$$e_0 = \frac{R^* d^{-1} f}{R^* + 1} \left(\frac{1}{\mathbb{E}[R] + \sigma_R F^{-1}(1 - \alpha)} + 1 \right) \tag{15}$$

$$e_1 = d^{-1} f - \frac{R d^{-1} f}{R^* + 1} \left(\frac{R^*}{\mathbb{E}[R] + \sigma_R F^{-1}(1 - \alpha)} - 1 \right). \tag{16}$$

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[20] We impose the technical assumption that $\epsilon \neq 0$ to ensure equilibrium uniqueness. Given that ϵ can be chosen to be arbitrarily small, this assumption has no bearing on our results. In fact, we present our analytical results for the case that $\epsilon \to 0$.

Equations (14)–(16) provide a complete characterization of equilibrium in the economy with value-at-risk constraints. Furthermore, they imply that foreign currency's excess return is equal to

$$\phi = (1+1/R)\left(\frac{R^*+1}{1+(\mathbb{E}[R]+\sigma_R F^{-1}(1-\alpha))^{-1}}\right) - R^*. \tag{17}$$

The above expression immediately implies that an increase in monetary policy uncertainty increases excess returns ($\partial\phi/\partial\sigma_R > 0$), consistent with our result in Proposition 1. Furthermore, an ex post adoption of an expansionary policy in the U.S. — which corresponds to a decrease in R — increases the difference between foreign currency's excess returns on announcement and non-announcement days ($\partial^2\phi/\partial R\partial\sigma_R < 0$), an observation that is in line with Proposition 3. Finally, it is easy to verify that, in line with Proposition 2, a higher interest rate in the foreign country not only increases expected excess returns ($\partial\mathbb{E}[\phi]/\partial R^* > 0$), but also increases the mean returns that are earned in compensation for higher monetary policy uncertainty ($\partial^2\mathbb{E}[\phi]/\partial R^*\partial\sigma_R > 0$).

In summary, the above discussion illustrates that our baseline model's insights presented in Section 2 are not sensitive to the specific nature of the limited commitment constraint and hold for any constraint that induces a downward-sloping demand for risk taking by financiers.

B Proofs and Derivations

Proof of Lemma 1 Recall from (10) that Γ is determined as the solution to the equation

$$d^2\Gamma(\Gamma+c)^2 - \gamma\sigma_f^2(\Gamma+c)^2 - \gamma b^2\sigma_R^2 = 0. \tag{18}$$

Therefore, by the implicit function theorem,

$$\frac{\partial\Gamma}{\partial\sigma_R^2} = \frac{\gamma b^2}{\Gamma+c}\left(3d^2\Gamma + d^2c - 2\gamma\sigma_f^2\right)^{-1}.$$

Replacing for $\gamma\sigma_f^2 = d^2\Gamma - \gamma b^2\sigma_R^2(\Gamma+c)^{-2}$ from (18) in the above expression implies that

$$\frac{\partial\Gamma}{\partial\sigma_R^2} = \frac{\gamma b^2}{\Gamma+c}\left(d^2\Gamma + d^2c + \frac{2\gamma b^2\sigma_R^2}{(\Gamma+c)^2}\right)^{-1}.$$

The right-hand side of the above equation is strictly positive, thus implying that Γ is strictly increasing in σ_R. □

Proof of Lemma 2 Since $R^* > \mathbb{E}[R]$, the characterization in (7) implies that an increase in Γ reduces e_0. On the other hand, equation (8) implies that increasing Γ increases e_1. As a result, $\phi = (R^*e_1)/(Re_0)$ is strictly increasing in Γ. □

Proof of Proposition 2 We start by proving that $d\mathbb{E}[\phi]/dR^* > 0$. Note that

$$\frac{d\mathbb{E}[\phi]}{dR^*} = \frac{\partial \mathbb{E}[\phi]}{\partial \Gamma}\frac{\partial \Gamma}{\partial R^*} + \frac{\partial \mathbb{E}[\phi]}{\partial R^*}.$$

Lemma 2 guarantees that $\partial\mathbb{E}[\phi]/\partial\Gamma$ is positive. Therefore, the proof is complete once we show that $\partial\Gamma/\partial R^*$ and $\partial\mathbb{E}[\phi]/\partial R^*$ are also positive.

We first show that $\partial\Gamma/\partial R^* \geq 0$. Recall from the proof of Lemma 1 that Γ satisfies equation (18). Therefore, by the implicit function theorem,

$$\frac{\partial \Gamma}{\partial R^*} = -\frac{2d\Gamma(\Gamma+c)\mathbb{E}[R] - 2d^{-1}\gamma\sigma_f^2(\Gamma+c)\mathbb{E}[R] - 2d^{-1}\gamma b f_0 \sigma_R^2}{d^2(\Gamma+c)^2 + 2d^2\Gamma(\Gamma+c) - 2\gamma\sigma_f^2(\Gamma+c)}.$$

Multiplying the numerator and denominator by $\Gamma + c$ and replacing for $d^2\Gamma(\Gamma+c)^2 - \gamma\sigma_f^2(\Gamma+c)^2$ in the denominator from (18) leads to

$$\frac{\partial \Gamma}{\partial R^*} = \frac{2\gamma b f_0 \sigma_R^2(\Gamma+c) - 2\mathbb{E}[R]\left(d^2\Gamma(\Gamma+c)^2 - \gamma\sigma_f^2(\Gamma+c)^2\right)}{d^3(\Gamma+c)^3 + 2\gamma d b^2 \sigma_R^2}.$$

On the other hand, equation (18) implies that $d^2\Gamma(\Gamma+c)^2 - \gamma\sigma_f^2(\Gamma+c)^2 = \gamma b^2\sigma_R^2$. Therefore,

$$\begin{aligned}\frac{\partial \Gamma}{\partial R^*} &= 2\gamma b \sigma_R^2\left(\frac{f_0(\Gamma+c) - b\mathbb{E}[R]}{d^3(\Gamma+c)^3 + 2\gamma d b^2\sigma_R^2}\right)\\ &= 2\gamma b f_0 \sigma_R^2\left(\frac{\Gamma d + \mathbb{E}[R] + \mathbb{E}^2[R]}{d^4(\Gamma+c)^3 + 2\gamma d^2 b^2 \sigma_R^2}\right), \end{aligned} \tag{19}$$

where we are using the fact that $b = d^{-1}f_0(R^* - \mathbb{E}[R])$ and $c = d^{-1}(1+R^*)\mathbb{E}[R]$. It is now immediate that the right-hand side of the above equation is always non-negative, thus guaranteeing that $\partial\Gamma/\partial R^* \geq 0$.

Next, we show that $\partial\mathbb{E}[\phi]/\partial R^* \geq 0$. To this end, note that the characterization in (7) and (8) implies that the equilibrium excess returns of the foreign currency is equal to

$$\phi = \frac{R^*(\Gamma f_1 d + f_1(R^*+1)\mathbb{E}[R] + R f_0 \mathbb{E}[R] - R R^* f_0)}{R f_0(\Gamma d + R^*(\mathbb{E}[R]+1))}.$$

As a result,

$$\mathbb{E}[\phi] = \frac{R^*(\mathbb{E}[R^{-1}]\Gamma d + (R^*+1)\mathbb{E}[R]\mathbb{E}[R^{-1}] + \mathbb{E}[R] - R^*)}{\Gamma d + R^*(\mathbb{E}[R]+1)}. \tag{20}$$

Differentiating the above expression with respect to R^* and some algebraic manipulations lead to

$$\frac{\partial \mathbb{E}[\phi]}{\partial R^*} = R^*\left(\mathbb{E}[R]\mathbb{E}[R^{-1}] - 1\right)\frac{2\Gamma d + R^*(\mathbb{E}[R]+1)}{(\Gamma d + R^*(\mathbb{E}[R]+1))^2} + \Gamma d\frac{\Gamma d\mathbb{E}[R^{-1}] + \mathbb{E}[R] + \mathbb{E}[R]\mathbb{E}[R^{-1}]}{(\Gamma d + R^*(\mathbb{E}[R]+1))^2}.$$

By Jensen's inequality, $\mathbb{E}[R]\mathbb{E}[R^{-1}] \geq 1$. Therefore, the right-hand side of the above expression is non-negative, thus completing the proof of the first statement.

We prove the second statement of the proposition assuming that $R^* \approx \mathbb{E}[R]$. Note that equation (20) can be rewritten as

$$\mathbb{E}[\phi] = R^*\mathbb{E}[R^{-1}] - R^*\left(1 + \mathbb{E}[R^{-1}]\right)\left(\frac{R^* - \mathbb{E}[R]}{\Gamma d + R^*(\mathbb{E}[R] + 1)}\right).$$

Differentiating the above expression with respect to σ_R implies that

$$\frac{\partial \mathbb{E}[\phi]}{\partial \sigma_R} = \frac{R^* d(R^* - \mathbb{E}[R])}{\left(\Gamma d + R^*(\mathbb{E}[R] + 1)\right)^2}\left(1 + \mathbb{E}[R^{-1}]\right)\frac{\partial \Gamma}{\partial \sigma_R}.$$

As a result, the derivate of the above expression with respect to R^* evaluated in the neighborhood of $\mathbb{E}[R]$ is given by

$$\left.\frac{\partial^2 \mathbb{E}[\phi]}{\partial R^* \partial \sigma_R}\right|_{R^* = \mathbb{E}[R]} = \frac{R^* d\left(1 + \mathbb{E}[R^{-1}]\right)}{\left(\Gamma d + R^*(\mathbb{E}[R] + 1)\right)^2}\frac{\partial \Gamma}{\partial \sigma_R}.$$

On the other hand, recall from (19) that $\partial \Gamma / \partial R^* > 0$, thus guaranteeing that the right-hand side of the above expression is positive. $\square$

Proof of Proposition 3 Equations (7) and (8) imply that the foreign currency's excess return is given by

$$\phi = \frac{R^* f_1}{R f_0} - R^*\left(\frac{f_1 + R f_0}{R f_0}\right)\left(\frac{R^* - \mathbb{E}[R]}{\Gamma d + R^*(\mathbb{E}[R] + 1)}\right).$$

As a result,

$$\frac{\partial \phi}{\partial \sigma_R} = \frac{R^* d(R^* - \mathbb{E}[R])}{(\Gamma d + R^*(\mathbb{E}[R] + 1))^2}\left(1 + \frac{f_1}{R f_0}\right)\frac{\partial \Gamma}{\partial \sigma_R}.$$

By Lemma 1, the term $\partial \Gamma / \partial \sigma_R$ is positive. Therefore, it is immediate that the right-hand side of the above equation is decreasing in R, thus guaranteeing that $\partial^2 \phi / \partial R \partial \sigma_R < 0$. $\square$

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