Currency Returns in Different Time Zones

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ABSTRACT

Currencies have different returns during US and foreign business hours. I propose a risk-based explanation for this pattern: Because news about US growth prospects arrives mostly during US business hours, US investors are exposed to a higher long-run risk and require more compensation for holding risky currencies in these hours. This explanation predicts that the currency return differentials between US and foreign business hours are greater for riskier currencies, and further widen when their exchange rates become more volatile. Both predictions are confirmed in the data. These findings show currency risk premia observed at lower frequencies also manifest themselves in intraday and overnight returns, and support exchange rate models with recursive preferences and long-run risks.

JEL classification: F31, G15

Keywords: Exchange Rates, Currency Risk Premia, Intraday and Overnight Returns, Long-Run Risks

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Currencies returns vary across time zones. Take Figure 1(a) as an example. The Euro has a *positive* average return against the dollar during US business hours, and a *negative* average return outside US business hours. Over the past 10 years, the Euro's cumulative returns during US and foreign business hours keep diverging, although its exchange rate remains stable. A simple strategy that longs the Euro during US business hours and shorts the Euro during foreign business hours has an annualized Sharpe ratio of 0.97 before transaction costs, and 0.25 after adjusting for the bid-ask spread from indicative quotes. Previous literature (Cornett, Schwarz, and Szakmary (1995); Ranaldo (2009); Breedon and Ranaldo (2013)) documents these patterns and shows they are consistent with order flows, concluding that currency markets are segmented and market participants are net buyers of foreign currencies in their local business hours.

In this paper, I propose a risk-based explanation of this pattern. Because US macroeconomic news arrives mostly during US business hours and contains potentially negative information about future growth prospects, US investors with recursive preferences will require a higher risk compensation in these hours. Because the Euro is a risky currency, it has to compensate the US investors for bearing the exchange rate risk by appreciating during US business hours.

In contrast, because the Japanese Yen provides a hedge against the news about US fundamentals, the US investors accept an even lower risk premium to hold the Japanese Yen during US business hours. Consistent with this argument, Figure 1(b) shows that the Yen has a *negative* average return against the dollar during US business hours, and a *positive* average return outside US business hours.

This relationship between a currency's risk exposure and its return differential between US and foreign business hours is more general. In Figure 2, I show that a currency with a higher exposure to the US stock market tends to have a greater return differential between US and foreign business

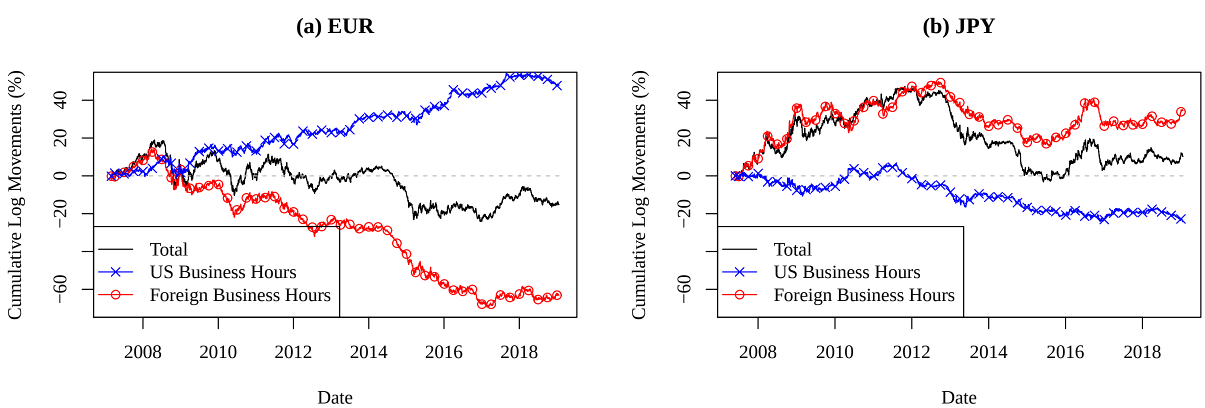

Figure 1. Cumulative Exchange Rate Movements in Different Business Hours. The blue line plots the cumulative exchange rate movement during US business hours (10AM—4PM, New York time). The red line plots the cumulative exchange rate movement outside US foreign hours. The black line is their sum, representing the aggregate exchange rate movement. A positive value means a stronger foreign currency.

hours: Because the Euro tends to depreciate when the US stock market crashes, the Euro has a higher average return during US business hours than during foreign business hours. In comparison, as the Hong Kong dollar does not comove with the US stock market, its return differential between different time zones is almost zero. On the other extreme, because the Japanese Yen tends to appreciate when the US stock market crashes, its average return during US business hours is lower than its average return during foreign business hours.

These results are consistent with an extension of the long-run risk model (Bansal and Yaron (2004); Bansal, Kiku, and Yaron (2009, 2010, 2016); Bansal and Shaliastovich (2013); Colacito and Croce (2011, 2013); Colacito, Croce, Gavazzoni, and Ready (2018)). To model the more frequent arrival of US macroeconomic news during US business hours, I assume the long-run growth rate of the US consumption is more volatile during US business hours. Because the US investors with recursive preferences are concerned about the long-run growth rate, they require a higher risk premium during US business hours. Then, a currency with a higher exposure to the US long-run growth rate not only provides a higher return on average but also appreciates during US business hours. In this way, this model connects currency risk premia observable at lower frequencies to currency return differentials between time zones, confirming the positive relationship in Figure 2.

My model further predicts that the currency return differential between time zones widens when the exchange rate is more volatile. To test this prediction, I need to know when the exchange rate is more volatile ex-ante. Since a higher exchange rate volatility in a week predicts a higher exchange rate volatility in the following week, I can examine the expected currency return differential on the exchange rate volatility in the previous week.

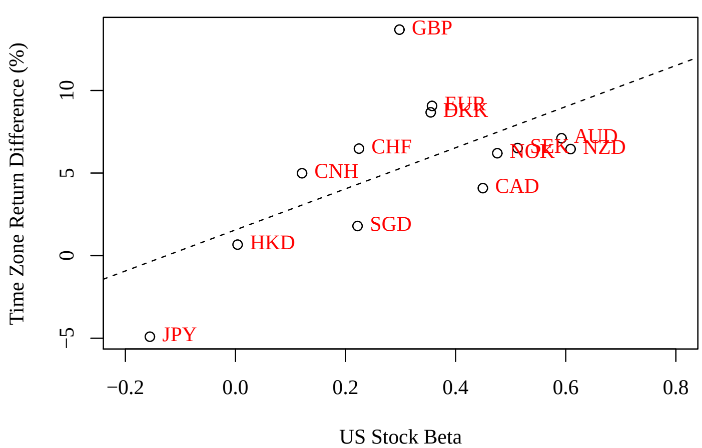

Figure 2. Currency Return Differential and US Stock Beta. I plot the difference in each currency's average excess returns between US and foreign business hours against the currency's beta with respect to the US stock return. The average excess returns are annualized, and the stock beta is measured at the monthly frequency.

Consistent with my model's prediction, the expected currency return differential between time zones is time-varying. For example, the Euro has a higher expected return during US business hours when it is predictably more volatile: In the bottom 25% of the weeks in terms of the Euro's volatility, the average difference in the Euro's excess returns between US and foreign business hours is 0.72% per annum in the following week. In the top 25% of the weeks, the average difference is 18.82%. The opposite is true for the Japanese Yen: The average difference in the Japanese Yen's excess returns between US and foreign business hours is −0.26% per annum for the 25% of the weeks when the Yen is the least predictably volatile, and −17.55% for the 25% of the weeks when it is the most predictably volatile.

In summary, this paper offers a risk-based explanation for currency returns in different time zones. It contributes to three literatures. First, past research has documented circadian variations in asset returns. Cornett et al. (1995) report this pattern in currency futures from 1977 to 1991; Ranaldo (2009) documents the same pattern using spot exchange rates from 1993 to 2005; Breedon and Ranaldo (2013) find regularities in both exchange rates and order flows from 1997 to 2007. Bloomberg News also covers this pattern, and estimates the daily return differential between U.S. and European business hours to be 4 to 6 basis points[1]. Beyond currency markets, Kelly and Clark (2011); Lou, Polk, and Skouras (2015) document strong overnight and intraday variations in stock returns. Building upon these papers, my paper connects the circadian variations in currency returns to their risk exposures.

Second, the international finance literature has connected each currency's risk premium to its exposure to various risk factors. In particular, Lustig and Verdelhan (2007) show that the exposures to US consumption growth risk can explain currency risk premia. Bansal and Shaliastovich (2013); Colacito and Croce (2011, 2013); Colacito, Croce, Gavazzoni, and Ready (Forthcoming) further highlight the role of recursive preferences and long-run consumption growth[2]. My paper uncovers a new dimension of currency risk premia that is consistent with these models: Because the news about the long-run US consumption growth arrives more often during US business hours, riskier currencies also have higher expected returns during US business hours than during foreign business hours.

Third, past research has shown that macroeconomic announcements affect asset prices (Andersen, Bollerslev, Diebold, and Vega (2003, 2007); Faust, Rogers, Wang, and Wright (2007); Evans and Lyons (2008); Giannone, Reichlin, and Small (2008); Gilbert (2011); Gilbert, Scotti, Strasser, and Vega (2017)). A large literature focuses on FOMC announcements (Lucca and Moench (2015); Mueller, Tahbaz-Salehi, and Vedolin (2017); Borisenko and Pozdeev (2017); Cieslak, Morse, and Vissing-Jorgensen (2018); Karnaukh (2018); Ai and Bansal (2018)). My paper shows that because US macro announcements arrive during US business hours, they also raise currency risk premia in these hours.

[1] Isobel Finkel, 2016, "FX Trader Seeking to Beat Your Peers? Set Your Alarm For 3 A.M."

[2] For models of currency risk premia, also see Hassan (2013); Martin (2013); Verdelhan (2010); Gourio, Siemer, and Verdelhan (2013); Maggiori and Gabaix (2015); Lustig, Roussanov, and Verdelhan (2014); Heyerdahl-Larsen (2014); Stathopoulos (2016); Farhi and Gabaix (2016); Richmond (2016); Jiang (2018).

I. Model

A. Set-Up

Time is discrete, indexed by t. Let $t \in T_{US} \stackrel{\text{def}}{=} \{1, 3, 5, \ldots\}$ represent US business hours, and $t \in T_F \stackrel{\text{def}}{=} \{2, 4, 6, \ldots\}$ represent foreign business hours. There is no overlap between US business hours and foreign business hours, and two consecutive t's represent a full day.

I consider the US economy in which the representative investor has the following Epstein and Zin (1989) preference:

$$U_t = \left\{(1 - \delta C_t)^{1-1/\psi} + \delta \mathbb{E}_t[U_{t+1}^{1-\gamma}]^{(1-1/\psi)/(1-\gamma)}\right\}^{1/(1-1/\psi)},$$

where γ is the relative risk aversion and ψ is the intertemporal elasticity of substitution. In this model, markets are complete, and the investor prefers early resolution of uncertainty: $\gamma > 1 > 1/\psi$.

The equilibrium log pricing kernel m_{t+1} of the US investor is

$$m_{t+1} = \theta \log \delta - \frac{\theta}{\psi}\Delta c_{t+1} + (\theta - 1) r_{c,t+1},$$

where Δc_{t+1} is the equilibrium log consumption growth rate, $r_{c,t+1}$ is the log return of the consumption claim, and $\theta = (1 - \gamma)/(1 - 1/\psi) < 0$.

The US consumption follows an exogenous process with a long-run growth rate x_t:

$$\begin{aligned} \Delta c_{t+1} &= \mu + x_t + \eta \varepsilon_{c,t+1}, \\ x_{t+1} &= \rho x_t + \sigma_{t+1} \varepsilon_{x,t+1}. \end{aligned}$$

The consumption shock $\varepsilon_{c,t+1}$ and the long-run growth shock $\varepsilon_{x,t+1}$ are i.i.d. normal with zero mean, unit variance, and zero correlation. The volatility of the innovation to the long-run growth rate x_t is different in different business hours:

$$\sigma_{t+1} = \begin{cases} \sigma_{US}, & \text{if } t+1 \in T_{US}, \\ \sigma_F, & \text{if } t+1 \in T_F. \end{cases}$$

Because the news about the US long-run growth prospects arrive mostly during US business hours, the innovation to the long-run growth rate x_t has a higher volatility during US business hours:

$$\sigma_{US} > \sigma_F.$$

Lastly, let d_t denote the log dividend of the US stock market, and let $r_{m,t+1}$ denote the cum-dividend return of the US stock market. As in Bansal and Yaron (2004), the US stock dividend is a leveraged claim on the long-run consumption growth rate:

$$\Delta d_{t+1} \quad = \quad \mu_d + \phi x_t + \sigma_d \varepsilon_{d,t+1},$$

where ϕ is the leverage and $\varepsilon_{d,t+1}$ is an idiosyncratic, standard normal shock to the dividend.

B. Characterizations

Let P_t denote the ex-dividend price of the consumption claim, and let z_t denote the price-to-consumption ratio:

$$z_t \quad \stackrel{\text{def}}{=} \quad \log \frac{P_t}{C_t}.$$

By Campbell and Shiller (1988) approximation, the log return $r_{c,t+1}$ of the consumption claim can be expressed as

$$r_{c,t+1} \quad = \quad \kappa_0 + \kappa_1 z_{t+1} - z_t + \Delta c_{t+1},$$

where the coefficients κ_0 and κ_1 are

$$\begin{aligned} \kappa_1 \quad &= \quad 1/(1 + \exp(-\bar{z})), \\ \kappa_0 \quad &= \quad -\log \kappa_1 + (1 - \kappa_1) \log(1/\kappa_1 - 1). \end{aligned}$$

C. Currency Returns

Let $r_{f,t}$ denote the risk-free rate in the US, and let r^i_{t+1} denote a foreign currency's excess return. For simplicity, the currency return loads on the US long-run risk, but has no idiosyncratic risk:

$$r^i_{t+1} \quad = \quad \mathbb{E}_t[r^i_{t+1}] + \beta^i \omega \varepsilon_{x,t+1}.$$

The loading on the US long-run growth shock is $\beta^i \omega$. ω is a constant that applies to all foreign currencies. A higher ω implies higher exchange rate volatilities for all foreign currencies. On the other hand, β^i can be different for different countries, which I take as given. As discussed in the literature review, there is a large literature in international finance that seeks to explain this cross-country heterogeneity.

Since each currency's excess return is priced by the US investors' pricing kernel, it satisfies the following Euler equation:

$$1 \quad = \quad \mathbb{E}_t[\exp(m_{t+1} + r_{f,t} + r^i_{t+1})].$$

Let r^i_{US} and $r^i_{Foreign}$ denote the unconditional average excess return of currency i during US and foreign business hours:

$$\begin{aligned} r^i_{US} &\stackrel{\text{def}}{=} \mathbb{E}\left[r^i_{t+1}|t+1 \in T_{US}\right], \\ r^i_F &\stackrel{\text{def}}{=} \mathbb{E}\left[r^i_{t+1}|t+1 \in T_F\right]. \end{aligned}$$

The following proposition characterizes the currency returns across time zones:

PROPOSITION 1: *The difference in currency i's excess returns between US and foreign business hours can be expressed as*

$$r^i_{US} - r^i_F = \frac{\gamma - 1/\psi}{1/\kappa_1 - \rho}(\sigma_{US} - \sigma_F) \cdot \beta^i \omega. \tag{1}$$

Since $\gamma > 1/\psi$, $1/\kappa_1 > 1 > \rho$, and $\sigma_{US} > \sigma_F$, the currency return differential $r^i_{US} - r^i_F$ is increasing in β^i and ω. This proposition gives rise to two testable implications: First, this currency's return differential between US and foreign business hours can be related to its risk exposure at a lower frequency. Start with $t \in T_F$. Then, period t plus period $t+1$ is a full trading day. Suppose there are N trading days in each month; then, there are $2N$ periods in each month. Let k be the index of the month. I regress the currency's monthly excess return on the US stock market's monthly excess return:

$$\sum_{t=1}^{2N} r^i_{2Nk+t} = a^i + b^i \cdot \sum_{t=1}^{2N}(r_{m,2Nk+t} - r_{f,2Nk+t-1}) + e^i_{2Nk+2N}.$$

The coefficient b^i is defined as currency i's stock beta. In the Appendix, I show a currency's stock beta b^i is proportional to its risk exposure β^i, which leads to the following result.

COROLLARY 1: *Across different currencies, currency i's return difference* $r^i_{US} - r^i_F$ *between US and foreign business hours is increasing in its stock beta* b^i.

In particular, a currency with a positive stock beta b^i tends to have a higher excess return during US business hours than during foreign business hours, while a currency with a negative stock beta b^i tends to have a lower excess return during US business hours than during foreign business hours.

Second, ω represents the overall volatility in the foreign exchange market. The US investor requires a higher risk premium if the exchange rate volatility is higher.

COROLLARY 2: *Across different replica of this model, the return difference* $r^i_{US} - r^i_F$ *between US and foreign business hours widens if* ω *is larger.*

II. Empirical Results

A. Market Overview and Data Source

The foreign exchange market is the largest financial market in the world, with a daily turnover of 5 trillion dollars in 2016[3]. This market has two distinctive features. First, a small number of liquidity providers intermediate the majority of trading volume. Appendix Table IV reports the statistics from the Euromoney FX Survey 2018. 65% of total volume of currency trading runs through 10 intermediaries, which include banks, asset managers and a trading platform.

Second, this market opens 24 hours in each trading day. As intermediaries have branches all over the world, currency traders can always find a counterparty at any time of the day.

For notational convenience, time is indexed in a way different from the model. Let t be the index of trading days, and let e^i denote the nominal exchange rate of foreign currency i against the dollar. A higher value means a stronger foreign currency. For each foreign currency i, I define the *US business hour return* as the log exchange rate movement from 10AM to 4PM New York time:

$$r^i_{US,t} \overset{\text{def}}{=} \log \mathrm{e}^i_{t,4PM} - \log \mathrm{e}^i_{t,10AM}.$$

I use 10AM New York time (4PM London time) as the start of US business hours because the WM/Reuters benchmark rates (the "London Fix Rates") are determined based on transactions in the interbank market during the 60-second window around 4PM London time. These benchmark rates are offered by banks as the close prices. Appendix Tables VIII, IX, X, and XI show robustness tests under alternative definitions of business hours.

Foreign business hours precede US business hours. I define the *foreign business hour return* as the log exchange rate movement from 4PM New York time in the previous trading day to 10AM New York time:

$$r^i_{Foreign,t} \overset{\text{def}}{=} \log \mathrm{e}^i_{t,10AM} - \log \mathrm{e}^i_{t-1,4PM}.$$

The close-to-close exchange rate movement is the sum of US business hour return and the foreign business hour return in the same trading day:

$$r^i_t \overset{\text{def}}{=} r^i_{US,t} + r^i_{Foreign,t} = \log \mathrm{e}^i_{t,4PM} - \log \mathrm{e}^i_{t-1,4PM}.$$

These returns are not adjusted by interest rates because intraday currency traders do not pay interest rates as long as they liquidate their positions at 5pm New York time, which marks the end of a 24-hour trading cycle. These two returns represent the intraday and overnight currency excess returns in my model.

The exchange rates are obtained from the interbank market through Bloomberg BFIX database, which reports exchange rates every 30 minutes. My sample includes 13 commonly traded foreign

[3] See 2016 BIS triennial survey of foreign exchange and OTC derivatives trading.

currencies: GBP, EUR, DKK, AUD, SEK, CHF, NZD, NOK, CNH, CAD, SGD, HKD, and JPY. Most countries have time series starting at 2007-03; JPY and CHF starts at 2007-05, and CNH start at 2012-01.

US stock returns are value-weighted and cum-dividend, downloaded from CRSP. Risk-free rates are the 1-month T-Bill return is from Ibbotson and Associates, downloaded from Ken French's website.

B. Currency Returns and Risk Exposures

Corollary 1 links each currency's risk exposure at monthly frequency to the difference in its returns between US and foreign business hours. To test this claim, Table I reports each foreign currency's excess returns in US and foreign business hours. For example, the Euro appreciates by 3.91% per annum during US business hours and depreciates by 5.15% per annum during foreign business hours. The difference between the US business hour return and the foreign business hour return is 9.07% per annum. In comparison, the Euro depreciates by only 1.24% per annum during the sample period.

GBP (British Pound), AUD (Australian Dollar) and DKK (Danish Krone) also have higher returns during US business hours, while JPY (Japanese Yen) depreciates against the dollar during US business hours and appreciates during foreign business hours.

To measure the stock beta in Corollary 1, I regress each currency's monthly exchange rate movement on the concurrent cum-dividend excess return $r_{m,t} - r_{f,t-1}$ of the US stock market:

$$\sum_{month(t)=j} r_t^i = a_b^i + b^i \cdot \sum_{month(t)=j} (r_{m,t} - r_{f,t-1}) + \varepsilon_j^i; \tag{2}$$

in this regression, each month is an observation, and there are no overlapping days between observations.

The last column in Table I reports the result: Currencies that tend to appreciate during US business hours are positively exposed to the US stock market, while currencies that tend to depreciate during US business hours are negatively exposed.

Figure 2 at the beginning of this paper visualizes this alignment between the stock beta and the difference in currency returns between US and foreign business hours. If I regress each currency's annualized return difference $mean(r^i_{US,t} - r^i_{Foreign,t}) \times 252$ on the US stock beta b^i, the regression coefficient is 12%, the intercept is statistically insignificant, and the R^2 is 40%. In other words, a currency with a unit beta with respect to the US stock market tends to appreciate by 12% per annum during US business hours relative to foreign business hours, whereas a currency with a zero stock beta does not have higher returns during US business hours relative to foreign business hours. The risk exposure to the US stock market explains a significant fraction of variation in the difference in currency returns across time zones.

I consider the following robustness tests. First, Appendix Table V reports each currency's stock beta measured at the daily frequency. The relationship between a currency's return differential

Currency	$r^i_{US,t}$	$r^i_{Foreign,t}$	$r^i_{US,t} - r^i_{Foreign,t}$	$r^i_{US,t} + r^i_{Foreign,t}$	b^i
GBP	5.12	−8.56	13.68	−3.44	0.30
	(1.43)	(2.33)	(2.71)	(2.76)	(0.05)
EUR	3.91	−5.15	9.07	−1.24	0.36
	(1.56)	(2.22)	(2.72)	(2.71)	(0.06)
DKK	3.71	−4.97	8.68	−1.26	0.35
	(1.50)	(2.25)	(2.67)	(2.74)	(0.06)
AUD	3.16	−3.95	7.11	−0.78	0.59
	(2.12)	(3.09)	(3.58)	(3.90)	(0.08)
SEK	2.22	−4.29	6.51	−2.07	0.51
	(2.03)	(2.97)	(3.55)	(3.65)	(0.06)
CHF	4.10	−2.38	6.48	1.72	0.22
	(1.65)	(2.72)	(2.94)	(3.42)	(0.07)
NZD	3.06	−3.39	6.45	−0.34	0.61
	(2.28)	(3.23)	(3.95)	(3.96)	(0.08)
NOK	1.74	−4.46	6.20	−2.72	0.48
	(2.05)	(2.98)	(3.52)	(3.72)	(0.07)
CNH	1.90	−3.09	4.99	−1.18	0.12
	(0.65)	(1.47)	(1.61)	(1.61)	(0.05)
CAD	1.52	−2.57	4.09	−1.05	0.45
	(1.83)	(2.13)	(2.78)	(2.84)	(0.05)
SGD	1.38	−0.42	1.79	0.96	0.22
	(0.84)	(1.39)	(1.60)	(1.65)	(0.04)
HKD	0.32	−0.35	0.67	−0.03	0.00
	(0.08)	(0.14)	(0.16)	(0.16)	(0.00)
JPY	−2.02	2.89	−4.91	0.87	−0.16
	(1.60)	(2.57)	(3.00)	(3.06)	(0.07)

Table I Currency Returns in Different Time Zones. I report the annualized average returns during US business hours ($r^i_{US,t}$) and during foreign business hours ($r^i_{Foreign,t}$), as well as the annualized averages of their difference and sum. These returns are in percentage points. I also report the exchange rate movement's beta in Eq. (2) with respect to the US stock market return. Data are daily, from 2007-03 to 2019-01. Standard errors, calculated from 10,000 rounds of bootstrapping, are reported in parentheses.

across time zones and its stock beta is similar but weaker. Because of short-term reversals and lead-lag effects that are beyond my model, aggregating stock and currency returns at the monthly level allows better estimates of the stock beta.

Second, in the context of the long-run risk model, Bansal and Shaliastovich (2013); Colacito and Croce (2011, 2013); Colacito et al. (Forthcoming) show that currency forward premia also reflect currency risk exposures. Appendix Table VII and Figure 4 show that currencies with higher forward premia also tend to have higher US business hour returns than foreign business hour returns[4].

[4]Because European currencies have zero or negative interest rates since the financial crisis, they have negative forward premia despite being exposed to the US stock return. Therefore, I use the currency forward premia at the start of the sample period (2007-05) to proxy for currency risk exposures. I do not solve the puzzle why currency forward premia are disconnected from currency risk exposures after the financial crisis.

Lastly, previous literature also documents the difference in currency returns between US and foreign business hours in earlier sample periods. Ranaldo (2009) shows that between 1993 and 2005, this difference is 19.20% per annum for Swiss Francs (CHF), 16.10% for Pounds (GBP), 12.30% for Mark (DEM) and 13.00% for Euros (EUR). In contrast, this difference is only 0.60% per annum for Japanese Yen (JPY)[5].

C. *Time-Series Variation in Currency Risk Premia*

Corollary 2 characterizes the comparative static effect of exchange rate volatility on currency risk premia: If the exchange rate movements are more volatile, risky currencies have more positive excess returns during US business hours and safe currencies have more negative excess returns during US business hours.

To test this claim, I regard each week as a separate replica of my model. First, I show that the current week's exchange rate volatility can be predicted by the previous week's exchange rate volatility. I aggregate the data at the weekly level and regress the annualized volatility of the daily exchange rate over the current week on the annualized volatility of the daily exchange rate over the previous week:

$$\sqrt{252} \underset{week(t)=w}{sd} (\Delta e_t^i) \quad = \quad a_\delta^i + \delta^i \cdot \sqrt{252} \underset{week(t)=w-1}{sd} (\Delta e_t^i) + \varepsilon_w^i. \tag{3}$$

As shown in Table II, the coefficient δ^i is positive. When the exchange rate movement is more volatile in the past week, it tends to be more volatile in the current week.

Now that the exchange rate volatility can be predicted, I can examine whether the currency return differential widens when the exchange rate volatility is predictably higher. To do so, I regress the average difference in the annualized returns between US and foreign business hours over a week on the annualized volatility of the daily exchange rate over the previous week:

$$252 \underset{week(t)=w}{mean} (r_{US,t}^i - r_{Foreign,t}^i) \quad = \quad a_\gamma^i + \gamma^i \cdot \sqrt{252} \underset{week(t)=w-1}{sd} (\Delta e_t^i) + \varepsilon_w^i. \tag{4}$$

Table II reports the result. When the exchange rate movement is predictably more volatile, the British Pound has an even higher return during US business hours than during foreign business hours, whereas the Japanese Yen has an even lower return during US business hours than during foreign business hours. This result, however, is weaker for other currencies.

Appendix Table VI reports the same regressions aggregated at the monthly level: I use the exchange rate volatility in a month to predict the exchange rate volatility and the return differential between time zones in the following month. The results are consistent, but are statistically insignificant due to a smaller sample size.

[5]For these statistics, the US business hours are 7AM—7PM New York time and the foreign business hours are 7PM—7AM New York time. DEM data stop at 1998 and EUR data start from 1999.

Currency	$r^i_{US,t} - r^i_{Foreign,t}$	δ^i	s.e.	γ^i	s.e.
GBP	13.68	0.36	(0.06)	1.72	(0.93)
EUR	9.07	0.41	(0.06)	1.35	(0.82)
DKK	8.68	0.41	(0.05)	1.35	(0.80)
AUD	7.11	0.62	(0.10)	−0.18	(0.64)
SEK	6.51	0.47	(0.05)	0.95	(0.93)
CHF	6.48	0.23	(0.07)	−0.38	(0.69)
NZD	6.45	0.49	(0.08)	−0.67	(0.78)
NOK	6.20	0.42	(0.04)	0.16	(0.75)
CNH	4.99	0.34	(0.08)	1.42	(1.53)
CAD	4.09	0.53	(0.07)	0.67	(1.06)
SGD	1.79	0.45	(0.05)	0.80	(0.95)
HKD	0.67	0.51	(0.05)	−0.09	(0.98)
JPY	−4.91	0.38	(0.06)	−1.63	(0.62)

Table II Volatility and Currency Risk Premia. I report the annualized averages of currency return differentials between US and foreign business hours (in percentage points) and the regression coefficients in Eq. (3) and Eq. (4). Observations are aggregated at the weekly level, from 2007-03 to 2019-01. Standard errors are HAC-consistent.

III. Discussions

In this paper, I provide a risk-based explanation for the difference in currency returns during US and foreign business hours. Because news about US growth prospects arrives mostly during US business hours, US investors require higher risk premia to hold risky currencies in these hours.

FOMC announcements are a major type of US news that contains information about US growth prospects. To test whether the difference in currency returns between US and foreign business hours is particularly large on FOMC announcement days, I regress the currency returns during US and foreign business hours on whether the observation is during US business hours, whether the observation is on an FOMC announcement day, and their interaction:

$$r^i_{US,t} \text{ or } r^i_{Foreign,t} = a + b \cdot 1_{\text{US hours}} + c \cdot 1_{\text{FOMC}} + d \cdot 1_{\text{US hours}} 1_{\text{FOMC}} + \varepsilon_{h,t}; \quad (5)$$

as defined in the previous section, foreign business hours at date t precede US business hours at date t.

Table III reports the result. For risky currencies like GBP and EUR, the coefficient b is positive, indicating their returns are higher during US business hours *regardless of FOMC* announcements. The coefficient c is also positive, indicating their returns are higher during *both* US and foreign business hours in FOMC announcement days. The interaction term d, however, is statistically insignificant. The currency return differential between US and foreign business hours does not further widen on FOMC announcement days.

In the context of my model, this result indicates that FOMC announcements increase the volatility of the US long-run growth during both US and foreign business hours. The higher

Currency	$r^i_{US,t} - r^i_{Foreign,t}$	b	s.e.	c	s.e.	d	s.e.
GBP	13.68	0.06	(0.01)	0.13	(0.05)	−0.05	(0.08)
EUR	9.07	0.04	(0.01)	0.10	(0.04)	0.02	(0.08)
DKK	8.68	0.03	(0.01)	0.10	(0.04)	0.02	(0.08)
AUD	7.11	0.02	(0.01)	0.02	(0.07)	0.17	(0.12)
SEK	6.51	0.02	(0.01)	0.08	(0.06)	0.06	(0.11)
CHF	6.48	0.02	(0.01)	0.10	(0.05)	0.03	(0.10)
NZD	6.45	0.02	(0.02)	0.13	(0.07)	0.03	(0.12)
NOK	6.20	0.02	(0.01)	0.05	(0.07)	0.10	(0.10)
CNH	4.99	0.02	(0.01)	0.01	(0.03)	0.02	(0.04)
CAD	4.09	0.01	(0.01)	0.07	(0.05)	0.08	(0.08)
SGD	1.79	0.00	(0.01)	−0.03	(0.03)	0.07	(0.06)
HKD	0.67	0.00	(0.00)	0.00	(0.00)	−0.00	(0.00)
JPY	−4.91	−0.02	(0.01)	−0.05	(0.05)	0.01	(0.08)

Table III Currency Returns during FOMC Announcements. I report the annualized average difference in returns between US and foreign business hours (in percentage points) and the regression coefficients in Eq. (5). Data are daily, from 2007-03 to 2019-01. Standard errors are HAC-consistent.

volatility raises the average returns of risky foreign currencies, but does not increase the risk premium during US business hours more than during foreign business hours.

If so, the US long-run growth being more volatile during US business hours is a more general pattern. It is not restricted to FOMC announcement days, although the fact that the coefficient d is not significantly negative indicates that this effect also applies to FOMC announcement days. Indeed, major US macroeconomic announcements are evenly spread across US business hours in each month. Figure 3 plots the monthly cycle of these announcements in 2018. As these announcements arrive during US business hours, US investors are constantly more exposed to the long-run risk during US business hours than during foreign business hours.

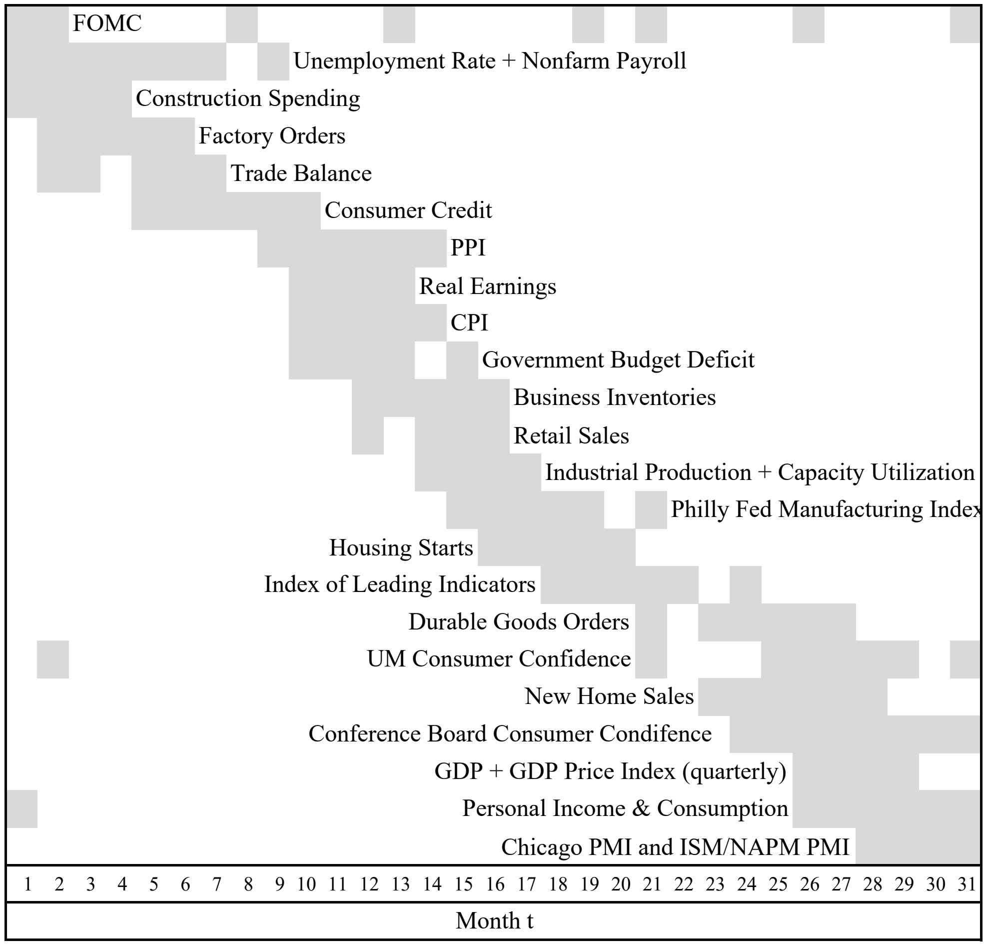

Figure 3. The monthly cycle of US announcements. I report the release dates of macroeconomic announcements in 2018. This figure is adapted from similar figures in Andersen et al. (2003); Gilbert et al. (2017).

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Appendix A. Proof

Model Characterization:

Let P_t denote the price of the consumption claim, and let z_t denote the ex-dividend price-to-consumption ratio. Conjecture

$$z_t \stackrel{\text{def}}{=} \log \frac{P_t}{C_t} = \begin{cases} A_{US} + B_{US} x_t, & \text{if } t \in T_{US}, \\ A_F + B_F x_t, & \text{if } t \in T_F. \end{cases}$$

By Campbell-Shiller approximation,

$$r_{c,t+1} = \kappa_0 + \kappa_1 z_{t+1} - z_t + \Delta c_{t+1}.$$

For $t \in T_F$,

$$\begin{aligned}
1 &= \mathbb{E}_t[\exp(m_{t+1} + r_{c,t+1})] \\
&= \mathbb{E}_t[\exp(\theta \log \delta + \theta(1 - \frac{1}{\psi})\Delta c_{t+1} + \theta\kappa_0 + \theta\kappa_1 z_{t+1} - \theta z_t)] \\
&= \mathbb{E}_t[\exp(\theta \log \delta + \theta(1 - \frac{1}{\psi})(\mu + x_t + \eta\varepsilon_{c,t+1}) + \theta\kappa_0 + \theta\kappa_1(A_{US} + B_{US} x_{t+1}) - \theta(A_F + B_F x_t))] \\
0 &= \theta \log \delta + \theta(1 - \frac{1}{\psi})(\mu + x_t) + \theta\kappa_0 + \theta\kappa_1(A_{US} + B_{US}\rho x_t) - \theta(A_F + B_F x_t) \\
&+ \frac{1}{2}(\theta(1 - \frac{1}{\psi}))^2\eta^2 + \frac{1}{2}(\theta\kappa_1 B_{US})^2\sigma_{US}^2,
\end{aligned}$$

which implies

$$\begin{aligned}
0 &= \theta \log \delta + \theta(1 - \frac{1}{\psi})\mu + \theta\kappa_0 + \theta\kappa_1 A_{US} - \theta A_F + \frac{1}{2}(\theta(1 - \frac{1}{\psi}))^2\eta^2 + \frac{1}{2}(\theta\kappa_1 B_{US})^2\sigma_{US}^2, \\
0 &= \theta(1 - \frac{1}{\psi}) + \theta\kappa_1 B_{US}\rho - \theta B_F.
\end{aligned}$$

For $t \in T_{US}$, we obtain a similar set of equations:

$$\begin{aligned}
0 &= \theta \log \delta + \theta(1 - \frac{1}{\psi})\mu + \theta\kappa_0 + \theta\kappa_1 A_F - \theta A_{US} + \frac{1}{2}(\theta(1 - \frac{1}{\psi}))^2\eta^2 + \frac{1}{2}(\theta\kappa_1 B_F)^2\sigma_F^2, \\
0 &= \theta(1 - \frac{1}{\psi}) + \theta\kappa_1 B_F\rho - \theta B_{US}.
\end{aligned}$$

So we confirm our conjecture, and

$$B_{US} = B_F = B \stackrel{\text{def}}{=} \frac{1 - 1/\psi}{1 - \kappa_1\rho}.$$

Proposition 1:

The Euler equation for the risk-free rate is

$$\begin{aligned} 1 &= \mathbb{E}_t[\exp(m_{t+1} + r_{f,t})] \\ 0 &= \mathbb{E}_t[m_{t+1}] + \frac{1}{2} var_t(m_{t+1}) + r_{f,t}. \end{aligned}$$

The Euler equation for currency i's excess return is

$$\begin{aligned} 1 &= \mathbb{E}_t[\exp(m_{t+1} + r_{f,t} + \mathbb{E}_t[r^i_{t+1}] + \beta^i \varepsilon_{x,t+1})] \\ 0 &= \mathbb{E}_t[m_{t+1}] + \frac{1}{2} var_t(m_{t+1}) + r_{f,t} + \mathbb{E}_t[r^i_{t+1}] + \frac{1}{2} var_t(r^i_{t+1}) + cov_t(m_{t+1}, r^i_{t+1}). \end{aligned}$$

Then

$$\begin{aligned} \mathbb{E}_t[r^i_{t+1}] &= -cov_t(m_{t+1}, r^i_{t+1}) - \frac{1}{2} var_t(r^i_{t+1}) \\ &= -(\theta - 1)\kappa_1 B \sigma_{t+1} \cdot \beta^i \omega - \frac{1}{2}(\beta^i \omega)^2. \end{aligned}$$

So

$$\begin{aligned} r^i_{US} - r^i_F &= \mathbb{E}\left[r^i_{t+1} | t+1 \in T_{US}\right] - \mathbb{E}\left[r^i_{t+1} | t+1 \in T_F\right] \\ &= \frac{\gamma - 1/\psi}{1/\kappa_1 - \rho}(\sigma_{US} - \sigma_F)\beta^i \omega. \end{aligned}$$

Corollary 1:

Let $z_{m,t}$ denote the ex-dividend price-to-dividend ratio of the US stock market. Similarly, the cum-dividend stock market return is

$$r_{m,t+1} = \kappa_{m,0} + \kappa_{m,1} z_{t+1} - z_t + \Delta d_{t+1},$$

and the ex-dividend price-to-dividend ratio can be expressed as

$$z_{m,t} = \begin{cases} A_{m,US} + B_m x_t, & \text{if } t \in T_{US}, \\ A_{m,F} + B_m x_t, & \text{if } t \in T_F. \end{cases}, \qquad B_m = \frac{\phi - 1/\psi}{1 - \kappa_{m,1}\rho}.$$

The stock beta b^i can be expressed as

$$b^i = \frac{cov\left(\sum_{t=1}^{2N}(r_{m,2Nk+t} - r_{f,2Nk+t-1}), \sum_{t=1}^{2N} r^i_{2Nk+t}\right)}{var\left(\sum_{t=1}^{2N}(r_{m,2Nk+t} - r_{f,2Nk+t-1})\right)}.$$

Since

$$\begin{aligned} r_{m,t+1} &= \kappa_{m,0} + \kappa_{m,1}(A_{m,US} + B_m(\rho x_t + \sigma_{US}\varepsilon_{x,t+1})) - (A_{m,F} + B_m x_t) + \mu_d + \phi x_t + \sigma_d \varepsilon_{d,t+1}, \\ r_{m,t} &= \kappa_{m,0} + \kappa_{m,1}(A_{m,F} + B_m(\rho x_{t-1} + \sigma_F \varepsilon_{x,t})) - (A_{m,US} + B_m x_{t-1}) + \mu_d + \phi x_{t-1} + \sigma_d \varepsilon_{d,t}, \end{aligned}$$

then the stock beta is

$$b^i = \frac{\omega\kappa_{m,1}B_m(\sigma_{US}+\sigma_F)}{(\kappa_{m,1}B_m\sigma_{US})^2+(\kappa_{m,1}B_m\sigma_F)^2+2\sigma_d^2}\cdot\beta^i,$$

which is indeed increasing in β^i,

Appendix B. Robustness Results

Appendix A. Euromoney Foreign Exchange Survey

Rank	Name	Market Share
1	JPMorgan	12.13%
2	UBS	8.25%
3	XTX Markets	7.36%
4	Bank of America Merrill Lynch	6.20%
5	Citi	6.16%
6	HSBC	5.58%
7	Goldman Sachs	5.53%
8	Deutsche Bank	5.41%
9	Standard Chartered	4.49%
10	State Street	4.37%
	Sum	65.48%

Table IV Top 10 Currency Intermediaries by Overall Market Share. This table reports the percentage of overall trading volume in the foreign exchange market. Data are from the Euromoney Foreign Exchange Survey 2018.

Appendix B. Results at different aggregation levels

Currency	$r^i_{US,t}$	$r^i_{Foreign,t}$	$r^i_{US,t} - r^i_{Foreign,t}$	$r^i_{US,t} + r^i_{Foreign,t}$	b^i
GBP	3.69	-7.13	10.82	-3.44	0.30
	(1.66)	(2.28)	(2.85)	(2.79)	(0.05)
EUR	4.01	-5.24	9.25	-1.24	0.36
	(1.74)	(2.14)	(2.73)	(2.80)	(0.06)
DKK	3.94	-5.19	9.13	-1.26	0.35
	(1.78)	(2.12)	(2.70)	(2.83)	(0.06)
AUD	1.06	-1.84	2.91	-0.78	0.59
	(2.40)	(3.01)	(3.87)	(3.84)	(0.08)
SEK	1.85	-3.92	5.78	-2.07	0.51
	(2.22)	(2.70)	(3.52)	(3.47)	(0.06)
CHF	5.71	-3.99	9.70	1.72	0.22
	(1.99)	(2.65)	(3.19)	(3.43)	(0.07)
NZD	1.53	-1.86	3.39	-0.34	0.61
	(2.42)	(3.12)	(4.01)	(3.88)	(0.07)
NOK	-0.54	-2.18	1.64	-2.72	0.48
	(2.24)	(2.81)	(3.54)	(3.65)	(0.07)
CNH	2.28	-3.46	5.75	-1.18	0.12
	(0.69)	(1.42)	(1.61)	(1.55)	(0.05)
CAD	-1.13	0.09	-1.22	-1.05	0.45
	(2.04)	(1.95)	(2.90)	(2.73)	(0.06)
SGD	1.24	-0.28	1.53	0.96	0.22
	(0.90)	(1.40)	(1.65)	(1.68)	(0.04)
HKD	0.31	-0.34	0.64	-0.03	0.00
	(0.09)	(0.14)	(0.16)	(0.16)	(0.00)
JPY	-1.40	2.26	-3.66	0.87	-0.16
	(1.80)	(2.36)	(2.81)	(3.11)	(0.07)

Table V Currency Returns in Different Time Zones, Aggregated at Daily Level. I report the annualized average returns during US business hours ($r^i_{US,t}$) and during foreign business hours ($r^i_{Foreign,t}$), as well as the annualized averages of their difference and sum. These returns are in percentage points. I also report the exchange rate movement's beta in Eq. (2) with respect to the US stock market return. Data are daily, from 2007-03 to 2019-01. Standard errors, calculated from 10,000 rounds of bootstrapping, are reported in parentheses.

Currency	$r^i_{US,t} - r^i_{Foreign,t}$	δ^i	s.e.	γ^i	s.e.
GBP	13.68	0.62	(0.14)	1.77	(1.41)
EUR	9.07	0.75	(0.07)	0.70	(1.22)
DKK	8.68	0.75	(0.07)	0.81	(1.22)
AUD	7.11	0.64	(0.08)	−0.88	(0.50)
SEK	6.51	0.78	(0.07)	−0.04	(1.37)
CHF	6.48	0.26	(0.19)	0.83	(0.32)
NZD	6.45	0.68	(0.05)	−1.47	(0.70)
NOK	6.20	0.72	(0.06)	−0.51	(1.18)
CNH	4.99	0.35	(0.11)	1.86	(1.83)
CAD	4.09	0.76	(0.07)	0.05	(0.93)
SGD	1.79	0.67	(0.08)	1.75	(0.94)
HKD	0.67	0.47	(0.07)	0.77	(1.07)
JPY	−4.91	0.57	(0.09)	−0.80	(0.82)

Table VI Volatility and Currency Risk Premia, Aggregated at Monthly Level. Same as Table VI. I report the annualized average difference in returns between US and foreign business hours (in percentage points) and the regression coefficients in Eq. (3) and Eq. (4). Data are aggregated at the monthly level, from 2007-03 to 2019-01. Standard errors are HAC-consistent.

Appendix C. Currency forward premia as a measure for currency risk exposures

Currency	$r^i_{US,t} - r^i_{Foreign,t}$	Currency forward premium
GBP	13.78	0.04
EUR	9.04	−0.35
DKK	8.64	−0.31
AUD	7.11	0.28
SEK	6.51	−0.49
CHF	6.46	−0.73
NZD	6.45	0.63
NOK	6.26	−0.24
CNH	5.03	0.23
CAD	4.09	−0.27
SGD	1.79	−0.58
HKD	0.66	−0.30
JPY	−4.91	−1.18

Table VII Currency Returns in Different Time Zones. I report the annualized average difference between US business hour returns and foreign business hour returns. These returns are in percentage points. I also the currency's forward premium against the US dollar. Data are daily, from 2007-03 to 2019-01.

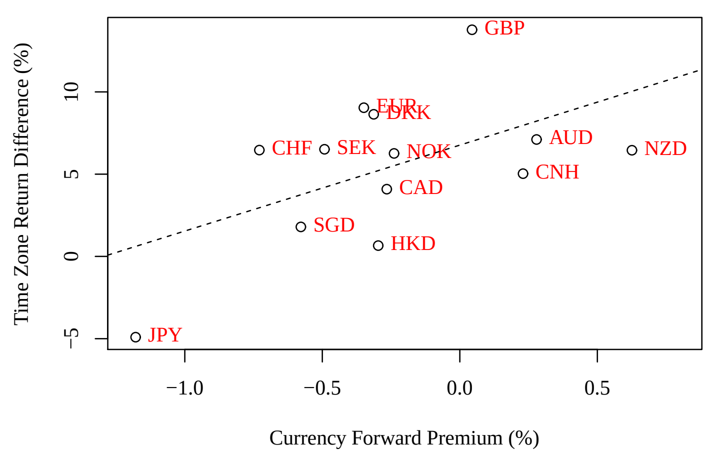

Figure 4. Currency Return Differential and Currency Forward Premium. I plot the difference in each currency's average excess returns between US and foreign business hours against the currency's forward premium against the US dollar. The average excess returns are annualized, and the forward premium is measured at the start of the sample period.

Appendix D. Alternative definitions of US and foreign business hours

Currency	$r^i_{US,t}$	$r^i_{Foreign,t}$	$r^i_{US,t} - r^i_{Foreign,t}$	$r^i_{US,t} + r^i_{Foreign,t}$	b^i
GBP	3.69	-7.13	10.82	-3.44	0.30
	(1.60)	(2.25)	(2.80)	(2.72)	(0.05)
EUR	4.01	-5.24	9.25	-1.24	0.36
	(1.85)	(2.08)	(2.74)	(2.82)	(0.06)
DKK	3.94	-5.19	9.13	-1.26	0.35
	(1.78)	(2.05)	(2.68)	(2.75)	(0.07)
AUD	1.06	-1.84	2.91	-0.78	0.59
	(2.49)	(2.93)	(3.66)	(4.03)	(0.09)
SEK	1.85	-3.92	5.78	-2.07	0.51
	(2.24)	(2.76)	(3.51)	(3.59)	(0.06)
CHF	5.71	-3.99	9.70	1.72	0.22
	(1.96)	(2.69)	(3.18)	(3.47)	(0.07)
NZD	1.53	-1.86	3.39	-0.34	0.61
	(2.47)	(3.16)	(4.06)	(3.96)	(0.07)
NOK	-0.54	-2.18	1.64	-2.72	0.48
	(2.21)	(2.83)	(3.66)	(3.52)	(0.07)
CNH	2.28	-3.46	5.75	-1.18	0.12
	(0.72)	(1.40)	(1.55)	(1.59)	(0.05)
CAD	-1.13	0.09	-1.22	-1.05	0.45
	(2.10)	(2.08)	(3.02)	(2.89)	(0.06)
SGD	1.24	-0.28	1.53	0.96	0.22
	(0.92)	(1.33)	(1.56)	(1.66)	(0.04)
HKD	0.31	-0.34	0.64	-0.03	0.00
	(0.09)	(0.13)	(0.16)	(0.16)	(0.00)
JPY	-1.40	2.26	-3.66	0.87	-0.16
	(1.80)	(2.34)	(2.90)	(2.99)	(0.07)

Table VIII Currency Returns in Different Time Zones, US Business hours are 9AM—5PM. I report the results in Table I, but define US business hours as 9AM—5PM New York time.

Currency	$r^i_{US,t} - r^i_{Foreign,t}$	δ^i	s.e.	γ^i	s.e.
GBP	10.82	0.36	(0.06)	1.19	(1.01)
EUR	9.25	0.41	(0.06)	1.02	(1.00)
DKK	9.13	0.41	(0.05)	1.04	(0.98)
AUD	2.91	0.62	(0.10)	0.28	(0.83)
SEK	5.78	0.47	(0.05)	0.36	(0.98)
CHF	9.70	0.23	(0.07)	−0.56	(0.78)
NZD	3.39	0.49	(0.08)	−0.63	(0.88)
NOK	1.64	0.42	(0.04)	−0.54	(0.63)
CNH	5.75	0.35	(0.08)	1.98	(1.60)
CAD	−1.22	0.53	(0.07)	−0.50	(0.98)
SGD	1.53	0.45	(0.05)	0.43	(0.93)
HKD	0.64	0.51	(0.05)	0.14	(1.21)
JPY	−3.66	0.38	(0.06)	−1.79	(0.63)

Table IX Volatility and Currency Risk Premia, US Business hours are 9AM—5PM. I report the results in Table II, but define US business hours as 9AM—5PM New York time.

Currency	$r^i_{US,t}$	$r^i_{Foreign,t}$	$r^i_{US,t} - r^i_{Foreign,t}$	$r^i_{US,t} + r^i_{Foreign,t}$	b^i
GBP	3.90	-7.30	11.20	-3.40	0.30
	(1.87)	(2.18)	(2.99)	(2.74)	(0.05)
EUR	3.73	-4.98	8.71	-1.25	0.35
	(2.03)	(1.88)	(2.77)	(2.76)	(0.07)
DKK	3.67	-4.93	8.60	-1.27	0.35
	(1.98)	(1.87)	(2.80)	(2.64)	(0.06)
AUD	1.15	-1.98	3.13	-0.83	0.59
	(2.59)	(2.78)	(3.75)	(3.84)	(0.08)
SEK	0.34	-2.43	2.76	-2.09	0.51
	(2.45)	(2.59)	(3.56)	(3.58)	(0.06)
CHF	4.91	-3.19	8.11	1.72	0.23
	(2.10)	(2.47)	(3.21)	(3.27)	(0.07)
NZD	1.35	-1.70	3.05	-0.36	0.61
	(2.49)	(2.90)	(3.82)	(3.81)	(0.08)
NOK	-2.06	-0.71	-1.35	-2.76	0.47
	(2.51)	(2.60)	(3.55)	(3.68)	(0.07)
CNH	2.61	-3.84	6.46	-1.23	0.12
	(0.74)	(1.39)	(1.54)	(1.60)	(0.05)
CAD	-2.51	1.43	-3.94	-1.08	0.45
	(2.16)	(1.80)	(2.91)	(2.72)	(0.05)
SGD	2.85	-1.89	4.74	0.96	0.22
	(0.99)	(1.30)	(1.61)	(1.67)	(0.04)
HKD	0.37	-0.40	0.77	-0.03	0.00
	(0.09)	(0.13)	(0.16)	(0.16)	(0.00)
JPY	-0.56	1.45	-2.01	0.89	-0.16
	(2.07)	(2.18)	(2.96)	(3.05)	(0.07)

Table X Currency Returns in Different Time Zones, US Business hours are 8AM—4PM. I report the results in Table I, but define US business hours as 8AM—4PM New York time.

Currency	$r^i_{US,t} - r^i_{Foreign,t}$	δ^i	s.e.	γ^i	s.e.
GBP	11.20	0.37	(0.06)	1.31	(1.05)
EUR	8.71	0.40	(0.06)	0.87	(0.82)
DKK	8.60	0.41	(0.06)	0.79	(0.82)
AUD	3.13	0.60	(0.09)	1.29	(1.20)
SEK	2.76	0.48	(0.05)	−0.47	(0.92)
CHF	8.11	0.28	(0.05)	−0.32	(0.63)
NZD	3.05	0.50	(0.06)	0.44	(0.92)
NOK	−1.35	0.41	(0.04)	−0.89	(0.68)
CNH	6.46	0.36	(0.06)	0.84	(0.88)
CAD	−3.94	0.50	(0.06)	−0.48	(0.93)
SGD	4.74	0.45	(0.05)	−0.31	(0.97)
HKD	0.77	0.54	(0.05)	0.63	(1.38)
JPY	−2.01	0.36	(0.05)	−2.08	(0.63)

Table XI Volatility and Currency Risk Premia, US Business hours are 8AM—4PM. I report the results in Table II, but define US business hours as 8AM—4PM New York time.