U.S. Risk and Treasury Convenience*

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Abstract

We document that, over the past two decades, investors revised-up their assessment of U.S. risk relative to other advanced economies, driven by perceptions of greater long-run risk. Analytically, we use a no-arbitrage framework to link U.S. relative long-run risk, which we infer from bond and equity premia, to long-run exchange-rate risk and the convenience yield on long-maturity U.S. Treasuries. Taking theory to the data, we find that an increase in U.S. long-run risk leads to a persistent fall in the long-run convenience yield of U.S. Treasuries, in line with a (perceived) worsening of U.S. fundamentals. Further, we show that U.S. monetary policy easings increase U.S. long-run risk and decrease the convenience yield on long-maturity U.S. Treasuries. Overall, our results suggest that the rise and fall, respectively, of long-run U.S. risk and Treasury convenience over the past 20 years are two sides of the same coin and have been driven by easy (unconventional) U.S. monetary policy.

Key Words: Convenience Yields; Exchange Rates; Long-Run Risk; U.S. Safety; Monetary Policy.

JEL Codes: F30; F31; G12.

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1 Introduction

With a disproportionate share of global debt issuance and trade invoicing denominated in U.S. dollars (e.g. Eichengreen, Hausmann, and Panizza, 2007; Bruno and Shin, 2015; Gopinath, Boz, Casas, Díez, Gourinchas, and Plagborg-Møller, 2020), the dollar plays a special role in the global financial system. The extent of this special role has traditionally been measured by exchange rates, in particular by deviations from uncovered interest parity (UIP), which serve as a barometer of relative risk (e.g. Backus, Foresi, and Telmer, 2001; Engel, 2016). The centrality of the U.S. gives rise to a unique risk-sharing arrangement in which the U.S. earns an exorbitant privilege on its external portfolio in 'normal' times, but insures the rest of the world through a dollar appreciation during periods of global stress (Gourinchas, Rey, and Govillot, 2010; Maggiori, 2017). The dollar and U.S. Treasuries are so perceived as safe because they are a good hedge for foreign investors.

More recently, perceptions about the relative safety of U.S. Treasuries and the dollar have been inferred from deviations from covered interest parity (CIP). As stressed by Du, Im, and Schreger (2018a), the U.S. Treasury premium, *vis-à-vis* other advanced economies, has tended to be positive, indicating that investors were willing to forego other higher-yield, risk-free government bonds in favor of convenient, liquid and safe U.S. Treasuries. An implication is that the U.S. earns implicit seigniorage from abroad as it can issue debt at a discount relative to other risk-free advanced economies (Jiang, Krishnamurthy, and Lustig, 2020). Recently, however, at longer maturities the Treasury "convenience yield" has fallen to zero, and even turned negative, suggesting that investors are no longer willing to forego return to hold the world's reserve asset and currency. While this fact has gained considerable attention (e.g. Du, Hébert, and Li, 2022), as stressed by Gourinchas (2021), the jury for a convincing explanation is still out.

In this paper, we reconsider the U.S.'s standing as the safe haven of the global financial system. Specifically, we ask: into which assets and at what maturities is this safety priced? Has the U.S.'s safe-haven status been eroded over time? If so, what is behind this erosion? To answer these questions, we link, both theoretically and empirically, three important asset markets: bond, equity and foreign exchange. The main contribution of this paper is to study the equilibrium joint determination of pecuniary dollar risk premia and non-pecuniary Treasury convenience yields in response to fluctuations in investors' perception of U.S. relative risk, particularly its long-run or permanent risk, which we infer from bond and equity premia, as well as in response to U.S. monetary policy shocks. We find that easy U.S. monetary policy has contributed to the measured decline in long-run U.S. safety in these three asset markets.

We start by showing that a rise in U.S. risk has also been priced-in to equity markets. Specifically, over the past two decades, equity premia, measured by excess returns, in the U.S. have risen *vis-à-vis* other G.7 countries.[1] According to a standard no-arbitrage framework, this can be interpreted as evidence of a rise in U.S. relative risk. To dig deeper, we turn to bond markets and draw on Alvarez and Jermann (2005) by decomposing the rise in relative "total" risk into a permanent component—equity premia net of term premia—and a transitory component—term premia. This decomposition allows us to refine the stylized fact: the rise in U.S. risk is due to a rise in permanent risk.

Motivated by the fall in long-maturity Treasury convenience yields and the rise in relative U.S. permanent risk, we bring theory to bear on how, in equilibrium, both pecuniary and non-pecuniary returns on dollar portfolios adjust to changes relative country risk. To this end, we specify a two-country no-arbitrage model where each country (the U.S. and Foreign) is populated by representative investors who trade in equities and short- and long-maturity bonds denominated in both dollars and foreign currency. Crucially, bonds offer a non-pecuniary convenience yield on top of a pecuniary return. While we build on the work of Backus, Foresi, and Telmer (2001), and more recently Lustig and Verdelhan (2019), Lustig, Stathopoulos, and Verdelhan (2019), and Jiang, Krishnamurthy, and Lustig (2021a), our model has the distinct feature of providing a unified framework with which to analyze the equilibrium adjustments of dollar risk premia and Treasury convenience yields to fluctuations in U.S. relative risk in both the short and long run.[2]

We test the model-implied relationships between U.S. relative risk, Treasury convenience yields and dollar risk premia by estimating panel regressions and VARs for the U.S. *vis-à-vis* other G.7 economies. As we show, the distinction between permanent and transitory risk turns out to be highly relevant in the data. We begin by showing, consistent with our model, that a rise in U.S. relative permanent risk leads to a significant and persistent fall in the long-maturity U.S. Treasury convenience yield. Importantly, we highlight the temporal-stability of this relationship by showing that greater U.S. permanent risk leads to an erosion in long-maturity Treasury convenience both before and after the Global Financial Crisis (GFC). In all, the empirical evidence suggests that the rise in U.S. permanent risk and the fall in long-maturity

[1] Campbell and Ammer (1993) and, more recently, Campbell et al. (2020) show that the majority of equity excess returns are due to risk premia. Further, like us, Farhi and Gourio (2018) document a sizeable increase in the U.S. equity risk premium over the past two decades.

[2] Using a model without convenience yields, Lustig, Stathopoulos, and Verdelhan (2019) show that a rise in permanent risk should be met by an increase expected pecuniary carry-trade returns on long-maturity bonds. However, despite a trend increase in U.S. permanent risk, we find no evidence of any trend in pecuniary dollar returns in the data. This highlights the importance of having a model that features non-pecuniary returns, which offer a second channel of adjustment to relative risk. In related work to ours, Jiang, Krishnamurthy, and Lustig (2021b) show how convenience yields can help resolve long-standing puzzles in exchange-rate determination.

convenience yields over the past two decades are two sides of the same coin.

Conversely, our model-implied relationship between U.S. relative total risk and short-maturity convenience yields is much less strong. We show this is because permanent and transitory innovations to U.S. risk have offsetting effects on short-maturity convenience. Specifically, while a rise in U.S. permanent risk induces a fall in short-maturity Treasury convenience yields, in line with a (perceived) worsening of U.S. fundamentals, a rise in U.S. transitory risk actually leads to an increase in the relative convenience of short-maturity Treasuries. In other words, as long as risk can be intertemporally smoothed in the bond market, an increase in U.S. risk does not undercut the U.S. Treasury premium, which may be a consequence of the U.S.'s short-run safe-haven status.[3]

We also show that an increase in U.S. total risk raises dollar risk premia on-impact, reflecting a depreciation of the U.S. dollar. Decomposing relative total risk into its permanent and transitory components, we show the impact of innovations to U.S. relative transitory risk on exchange-rate risk premia is larger than from innovations to U.S. permanent risk, a finding that corroborates the results of Lustig et al. (2019) and Lloyd and Marin (2020).[4]

Finally, while our model defines sharp equilibrium relations between relative risk, convenience yields and exchange rate risk premia for which we find strong evidence in the data, it leaves open the question of what underlies the rise in U.S. permanent risk and fall in long-maturity Treasury convenience yields over the past two decades. To address this, we augment our permanent-risk panel VAR with high-frequency-identified monetary policy shocks. In our baseline, we use the Bu, Rogers, and Wu (2021) monetary policy shock, which are constructed from interest-rate movements along the entire U.S. Treasury yield curve and so provide a unified measure of both conventional and unconventional U.S. monetary policy surprises. We find that a shock monetary policy easing triggers a considerable rise and fall, respectively, of U.S. relative permanent risk and long-maturity Treasury convenience. Further, when we re-estimate the VAR using distinct interest rate, forward guidance and asset-purchase shocks from Swanson (2021), we find the largest effects on U.S. permanent risk and long-run Treasury convenience arise from unconventional policy. In all, these results highlight the (potential) side-effects of unorthodox interest rate policy for the U.S.'s standing as the safe-haven.

[3]Arguably, facing transitory "business-cycle" risk investors have no better alternative than to hold short-maturity U.S. Treasuries, even if U.S. (transitory) risk is relatively high. As is well known, at the onset of the GFC, many investors still preferred U.S. dollar-denominated assets in spite of the fact that the crisis originated in the U.S.

[4]Since changes in relative permanent risk induce a significant response in relative transitory risk, the dollar's carry trade return on long-maturity bonds—the sum of the exchange rate risk premium and the relative term premium, is highly responsive to permanent risk shocks.

Literature Review: Our paper relates to several strands in the literature. First, to the literature examining the central role of the U.S. in the global financial system. Key features of the U.S.'s role, which are inevitably intertwined, include being the world safe-asset supplier (Bernanke, 2005; Gourinchas and Rey, 2007; Caballero et al., 2008; and Farhi and Maggiori, 2018); the influence of its monetary policy on capital flows and asset prices across the world i.e. the Global Financial Cycle (Rey, 2015; Miranda-Agrippino and Rey, 2020; and Jiang, Krishnamurthy, and Lustig, 2020); and the dollar's role as a safe-haven currency (Gourinchas et al., 2010; Maggiori, 2017; and Kekre and Lenel, 2021), among others, such as convenience yields, which we spotlight below. In this paper, we re-evaluate the U.S.'s standing as a safe-haven, particularly in the long-run, drawing on asset prices in bond, equity and foreign exchange markets, with our results having potential implications for the U.S.'s central role going forward.[5]

Second, we contribute to studies on U.S. Treasury convenience yields and on other dollar-denominated bonds. This literature can be separated into papers investigating the drivers of convenience yields (Krishnamurthy and Vissing-Jorgensen, 2012; Du et al., 2018a; Du, Tepper, and Verdelhan, 2018b, Liao and Zhang, 2020; and Liu, Schmid, and Yaron, 2020) and those using convenience yields to explain exchange rate dynamics (Engel and Wu, 2018; Krishnamurthy and Lustig, 2019; Valchev, 2020; Augustin et al., 2020; Jiang et al., 2021a; Jiang et al., 2021b; and Ostry, 2022). A recent paper by Du et al. (2022) also investigates what is behind the fall in long-maturity Treasury convenience.[6] Their explanation is the post-Global Financial Crisis U.S. fiscal expansion coupled with tighter financial regulations that moved primary dealers from being net-short to net-long U.S. Treasuries. While there are similarities between our theories insofar as U.S. monetary policy was used to assist in this fiscal expansion, there are several notable distinctions: (i) we document the fall in long-maturity convenience yields long pre-dates the Global Financial Crisis, with half of the decline occurring before the GFC; (ii) we highlight a relationship between investors' perceptions of U.S. risk and long-maturity Treasury convenience, for which we find compelling evidence in the data, whereas their framework is agnostic as to whether the U.S. has become more risky, even for fiscal sustainability reasons; and (iii) we use high-frequency-identified U.S. monetary policy shocks to measure effects, whereas they focus on trends in aggregate Treasury supply.

Third, we contribute to the literature on the exchange rate "disconnect" (Meese and Rogoff, 1983; Obstfeld and Rogoff, 2000; and Itskhoki and Mukhin, 2021). Many remedies for the failure

[5] Atkeson et al. (2022) show that the rise in relative U.S. equity excess returns, which they attribute to positive U.S. productivity surprises, is responsible for the post-GFC deterioration of the U.S. exorbitant privilege. This stands in contrast to our interpretation, as well as that of Farhi and Gourio (2018), who document a sizeable increase the U.S. equity risk premium over the past two decades.

[6] The also investigate the fall in the "swap spread", the spread between OIS swap rates and Treasury yields.

of Uncovered Interest Parity, in particular, have been advanced including convenience yields; imperfect financial markets (Jeanne and Rose, 2002; Gabaix and Maggiori, 2015); long-run risk (Colacito and Croce, 2011); disaster risk (Farhi and Gabaix, 2016); and transitory risk (Lloyd and Marin, 2020; Gourinchas, Ray, and Vayanos, 2022), among others. Lilley, Maggiori, Neiman, and Schreger (2019) document a "reconnect" following the GFC. Relative to these papers, we provide evidence that exchange rates were "connected" all along: empirical measures of the relative volatility of investors' stochastic discount factors across countries (Alvarez and Jermann, 2005) are systematically associated with the exchange-rate risk premium.

The remainder of this paper is structured as follows. In Section 2, we define our notation and describe our data. Section 3 introduces our measures of risk and documents stylised facts about the relative riskiness of the U.S. Section 4 outlines our asset-pricing setup and derives theoretical results, which we test in Section 5. Section 6 concludes.

2 Basic Environment and Data

In this section, we introduce the notation and theoretical framework used in this paper, and then describe our data.

2.1 Basic Environment

Within the setup we consider, there are two countries: Home (i.e. the U.S.) and Foreign, where Foreign variables are denoted with an asterisk $*$. Representative investors in each economy can trade in zero-coupon bonds of varying maturities $k = 1, 2, ..., \infty$ issued in both the Home and Foreign economies. The bonds pay a known return in local currency at maturity and are free from default risk. The fact investors can trade in Home and Foreign bonds gives rise to foreign exchange and the possibility of carry trade, from which returns can vary over the term structure. In addition, investors can trade in risky equity, both domestically and across borders.

We define $P_t^{(k)}$ as the date-t price of a Home zero-coupon bond of maturity k. The one-period holding return on this bond is $HPR_{t+1}^{(k)} = P_{t+1}^{(k-1)}/P_t^{(k)}$. So the log excess return on the Home k-period zero-coupon bond is defined as:

$$rx_{t+1}^{(k)} = \log\left(\frac{HPR_{t+1}^{(k)}}{R_t}\right) \tag{1}$$

where the Home risk-free rate is $R_t \equiv R_{t,1} = P_{t+1}^{(0)}/P_t^{(1)} = 1/P_t^{(1)}$. In logs, this is defined as $r_t \equiv \log(R_t)$. The expectation of this log excess return, $\mathbb{E}_t[rx_{t+1}^{(k)}]$, is termed the bond-risk or 'term' premium.

We define the nominal exchange rate $\mathcal{E}_t$ to have units of U.S. dollars per unit of Foreign currency. Therefore, an increase in $\mathcal{E}_t$ corresponds to a U.S. (Home) depreciation and a Foreign appreciation. The *ex post* log return from a one-period carry-trade strategy that goes long the Foreign risk-free bond and short the U.S. risk-free bond—the Uncovered Interest Parity (UIP) deviation—is:

$$rx_{t+1}^{FX} = \log\left(\frac{R_t^*}{R_t}\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right) = r_t^* - r_t + \Delta e_{t+1} \tag{2}$$

where $e_t \equiv \log(\mathcal{E}_t)$ and $\Delta e_{t+1} \equiv e_{t+1} - e_t$. The expected UIP deviation, $\mathbb{E}_t[rx_{t+1}^{FX}]$, is the exchange-rate risk premium.

In turn, the *ex post* log return on a one-period carry trade that goes long a k-period Foreign bond and short a k-period U.S. Treasury, $rx_{t+1}^{(k),CT}$, is equal to:

$$\begin{aligned} rx_{t+1}^{(k),CT} = \log\left(\frac{HPR_{t+1}^{(k),*}}{HPR_{t+1}^{(k)}}\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right) &= \log\left(\frac{R_t^*}{R_t}\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right) + \log\left(\frac{HPR_{t+1}^{(k),*}}{R_t^*}\right) - \log\left(\frac{HPR_{t+1}^{(k)}}{R_t}\right) \\ &\equiv rx_{t+1}^{FX} + rx_{t+1}^{(k),*} - rx_{t+1}^{(k)}, \end{aligned} \tag{3}$$

the UIP deviation plus the relative bond excess returns. From this definition, we see that $rx_{t+1}^{FX} = rx_{t+1}^{(1),CT}$ since $rx_{t+1}^{(1),*} = rx_{t+1}^{(1)} = 0$. We refer to $rx_{t+1}^{(k),CT}$ as the k-period carry-trade return.

In contrast to this uncovered trade, the annualized log return on a covered position that goes long a k-period Foreign bond and short a k-period U.S. Treasury (Home bond)—the Covered Interest Parity (CIP) deviation—can be expressed as:

$$CIP_{t,k} = \frac{1}{k}\log\left(\frac{R_{t,k}^*}{R_{t,k}}\frac{\mathcal{F}_{t,k}}{\mathcal{E}_t}\right) = \frac{1}{k}[r_{t,k}^* - r_{t,k} + f_{t,k} - e_t] \tag{4}$$

where $f_{t,k} \equiv \log(\mathcal{F}_{t,k})$ is the log of the k-period-ahead nominal forward exchange rate, with the same units as e_t. When $CIP_{t,k} > 0$, the pecuniary return on a synthetic U.S. dollar-denominated bond, $f_{t,k} - e_t + r_{t,k}^*$, is greater than the pecuniary return on a U.S. Treasury, $r_{t,k}$. To the extent that arbitraging CIP deviations is riskless, this implies the non-pecuniary return on the U.S. bond must be greater than that on the Foreign bond. As shown in Jiang et al. (2021a), this non-pecuniary return is a linear function of the so-called k-period U.S. Treasury convenience yield, which we denote by $\theta_{t,k}$.[7]

Finally, we define the annualized k-period gross equity return in the Home country as:

$$R^{eq}_{t+k} = \left(\frac{P^{eq}_{t+k}}{P^{eq}_{t}} \right)^{1/k} \tag{5}$$

where P^{eq}_{t+k} is the price of an equity index return k-periods-ahead. The Foreign equity return is defined analogously.

2.2 Data

Throughout, we focus our empirical analysis on G.7 countries (currencies): Australia (AUD), Canada (CAD), Switzerland (CHF), euro area/Germany (EUR), Japan (JPY), U.K. (GBP) and U.S. (USD). Exchange-rate data is from *Datastream*, and the U.S. is our base country among our sample of advanced economies. Our analysis is carried out using an unbalanced panel at a monthly frequency, over the period 1997:01-2020:12.[8]

We use information on the term structure of interest rates in government bond markets for each of these regions, which are highly liquid. Specifically, we use 6-month nominal zero-coupon bond yields in each jurisdiction as our measure of short-term 'safe' interest rates and 10-year nominal zero-coupon bond yields as our proxy for the long-term bond yield. Yield curves are obtained from a combination of sources, including national central banks, Gürkaynak, Sack, and Wright (2007), and Wright (2011).

Our measure of government-bond CIP deviations and, in turn, convenience yields is from Du et al. (2018a). Again, we use information on the term structure of these yields, focusing on the 6-month convenience yield as our proxy for short-term convenience, and the 10-year convenience yield as our measure of long-term convenience yields.[9]

Finally, we obtain gross equity price indices for each country in local currency from *MSCI*. Each index aggregates information on equity prices and gross dividends for the country's large and mid-cap public firms.[10]

[7] In Appendix B, we estimate the scalar that links the k-period CIP deviation with the convenience yield.
[8] The start of our sample is restricted by the convenience yield data from Du et al. (2018a). See Appendix A for details.
[9] Our 6-month convenience yield is derived from the Du et al. (2018a) 3-month and 1-year convenience yield data by linear interpolation, according to: $\theta_{t,6M} = \frac{2}{3}\theta_{t,3M} + \frac{1}{3}\theta_{t,1Y}$. We use the 6-month convenience yield to match the maturity from our zero-coupon bond data.
[10] For purposes of calculating the indices, firm dividends are re-invested back into the dividend-paying firm's equity.

3 The Evolution of U.S. Relative Risk

Building on the basic environment and using the data described above, in this section we document stylized facts for a variety of measures of U.S. relative risk. These facts motivate our analysis, by painting a picture of the evolution of risk in equity and bond markets—reflecting investors' stochastic discount factors (SDFs)—exchange rates and convenience yields. To this end, in section (3.1), we first introduce the Alvarez and Jermann (2005) decomposition of investors' SDFs. In section (3.2), we then use asset prices to measure the volatility of investors' SDFs, which reflect countries' SDF risk, document the evolution of U.S. SDF risk relative to its G.7 counterparts, and juxtapose this evolution against trends in dollar exchange-rate risk and the U.S. Treasury convenience yield over the past two decades.

3.1 Decomposing Investors' SDFs

Let the Home (Foreign) nominal pricing kernel in period t be denoted by Λ_t (Λ_t^*). These are stochastic processes that assign values to state-contingent payments. As is well known, if markets admit no arbitrage, they can be thought of as investors' marginal utility of wealth. So their volatility can capture variation in economic risk over time. We distinguish between the pricing kernel and the Home (Foreign) one-period stochastic discount factor (SDF), between periods t and $t+1$, which we denote by $M_{t+1} \equiv \Lambda_{t+1}/\Lambda_t$ ($M_{t+1}^* \equiv \Lambda_{t+1}^*/\Lambda_t^*$).

Throughout, we assume that the SDFs and returns are jointly stationary and ergodic. Following Alvarez and Jermann (2005), we decompose the Home pricing kernel Λ_t into two components:

$$\Lambda_t = \Lambda_t^{\mathbb{P}} \Lambda_t^{\mathbb{T}} \tag{6}$$

where $\Lambda_t^{\mathbb{P}}$ is a martingale that captures the 'permanent' component of Λ_t, while $\Lambda_t^{\mathbb{T}}$ reflects the 'transitory' component. We decompose the Foreign pricing kernel analogously.

Under regularity conditions,[11] Alvarez and Jermann (2005) show that the permanent component is defined as $\mathbb{E}_t \Lambda_{t+1}^{\mathbb{P}} = \Lambda_t^{\mathbb{P}}$, where $\Lambda_t^{\mathbb{P}} = \lim_{k\to\infty} \frac{\mathbb{E}_t \Lambda_{t+k}}{\beta^{t+k}}$. The permanent measure is unaffected by information at time t that does not lead to revisions of the expected value of Λ in the long run. The transitory component is defined by: $\Lambda_t^{\mathbb{T}} = \lim_{k\to\infty} \frac{\beta^{t+k}}{\mathbb{E}_t[\Lambda_{t+k}]/\Lambda_t}$. This is equivalent to a scaled long-term interest rate.

[11]Specifically, the decomposition assumes: (i) that there is a number β such that $0 < \lim_{k\to\infty} \frac{\mathbb{E}[\Lambda_{t+k}]/\Lambda_t}{\beta^k} < \infty$ for all t; and (ii) for each $t+1$ there is a random variable x_{t+1} such that $\frac{\Lambda_{t+1}}{\beta^{t+1}} \frac{\mathbb{E}_{t+1}[\Lambda_{t+1+k}]/\Lambda_{t+1}}{\beta^k} \leq x_{t+1}$ almost surely, with $\mathbb{E}_t x_{t+1}$ finite for all k.

To assess the variation of the permanent component in the data, we again follow the methodology of Alvarez and Jermann (2005). Specifically, we employ the conditional volatility measure $\mathcal{L}_t(x_{t+1}) \equiv \log \mathbb{E}_t x_{t+1} - \mathbb{E}_t \log x_{t+1}$ to gauge a country's SDF risk.[12] Using this, the conditional volatility of the permanent component of investors' SDFs satisfies:

$$\mathcal{L}_t\left(M^{\mathbb{P}}_{t+1}\right) \geq \mathbb{E}_t \log \frac{R^{eq}_{t+1}}{R_t} - \mathbb{E}_t rx^{(\infty)}_{t+1} \tag{7}$$

where R^{eq}_{t+1} denotes the return on an equity index—as defined in equation (5)—and $rx^{(\infty)}_{t+1} = \lim_{k\to\infty} rx^{(k)}_{t+1}$. This inequality bounds the conditional volatility of the permanent component of the representative investor's SDF—the measure of a country's permanent risk—such that it is at least as large as the difference between the expected log excess return on risky equities—the first term on the right-hand side of expression (7)—relative to the return of the asymptotic discount bond—the second term.[13]

The conditional volatility of the permanent component can be scaled relative to the conditional volatility of the overall SDF—the measure of overall risk—by noting that:

$$\mathcal{L}_t\left(M_{t+1}\right) = \mathcal{L}_t\left(M^{\mathbb{P}}_{t+1}\right) + \mathbb{E}_t rx^{(\infty)}_{t+1} \tag{8}$$

which, using equation (7), implies that

$$\mathcal{L}_t\left(M_{t+1}\right) \geq \mathbb{E}_t \log \frac{R^{eq}_{t+1}}{R_t}. \tag{9}$$

The volatility bounds in equations (7) and (9) admit a helpful intuition. In many macroeconomic models, the equity of a country's representative firm can be viewed as a claim to the country's path of future output. As such, the expected equity return $\mathbb{E}_t \log R^{eq}_{t+1}$ prices the entirety of the country's (output) risk—both permanent and transitory. Thus, expression (9) relates the conditional volatility of the overall SDF to the country's total (permanent plus transitory) risk.

Furthermore, the excess return on a k-period bond $\mathbb{E}_t rx^{(k)}_{t+1}$, the k-period term premium, is an indicator of changes in the expected path of interest rates from t to $t+k$. These interest rates price only the risk that can be smoothed by trading bonds between t and $t+k$. As $k \to \infty$, the

[12]This measure of conditional volatility $\mathcal{L}_t(x)$, often referred to as Theil (1967)'s second conditional entropy measure, is 0 if $\text{var}_t(x) = 0$. But the reverse is not true. As a special case, if x_{t+1} is log-normally distributed, then $\mathcal{L}_t(x_{t+1}) = \frac{1}{2}\text{var}_t(x_{t+1})$. In general, however, the conditional volatility $\mathcal{L}_t(x_{t+1})$ is equal to one half the variance x_{t+1} plus all higher-order cumulants.

[13]Inequality (7) holds for any risky asset, but the right-hand side is maximised by using the return to a country's equity index.

infinite-maturity term premium captures the entirety of tradeable or transitory (output) risk. As such, the expected equity net infinite-maturity term premium of a country from expression (7), $\mathbb{E}_t \log(R^{eq}_{t+1}/R_t) - \mathbb{E}_t rx^{(\infty)}_{t+1}$, prices a country's permanent (output) risk only.[14]

To take these measures of relative SDF risk to the data, we first maximize the size of the lower bounds in (7) and (9), respectively, by using equity index returns. We then assume the bounds hold with equality.[15] This enables us to define the U.S.'s overall and permanent risk *relative* to country i's, respectively, as:

$$\begin{aligned} \mathrm{D}\mathcal{L}_t \left(M_{i,t+1}\right) &\equiv \mathcal{L}_t \left(M_{US,t+1}\right) - \mathcal{L}_t \left(M_{i,t+1}\right) \\ \mathrm{D}\mathcal{L}_t \left(M^{\mathbb{P}}_{i,t+1}\right) &\equiv \mathcal{L}_t \left(M^{\mathbb{P}}_{US,t+1}\right) - \mathcal{L}_t \left(M^{\mathbb{P}}_{i,t+1}\right). \end{aligned} \tag{10}$$

Moreover, throughout the paper, we follow a common approach in our baseline specification by proxying *ex ante* expected exchange-rate, bond and equity movements with *ex post* realizations (Alvarez and Jermann, 2005; Lustig et al., 2019). In other words, we carry out our empirical exercises under the assumption of rational expectations. Further, when deriving empirical proxies for the infinite-maturity limit, we use data for the relevant ten-year tenor.

3.2 Stylized Facts on U.S. Relative SDF Risk and its Transmission

Figure 1 presents our first stylized fact, showing that the U.S.'s overall SDF risk, proxied by its equity excess return, has risen considerably over the past two decades relative to a panel of advanced (G.7) economies. This is the case both when U.S. SDF risk is compared to the average SDF risk of G.7 economies (Panel 1a), as well as on a country-by-country basis when the time series is split into pre- and post-GFC sub-samples (Panel 1b). Using the Alvarez and Jermann (2005) decomposition introduced earlier, the lower two panels in Figure 1 highlight that the increase in U.S. relative risk has been driven by a rise in the U.S.'s relative *permanent* SDF risk, measured by the U.S.'s relative equity-net-term premium. This again holds both as an average across countries (Panel 1c) and for each country individually (Panel 1d).[16]

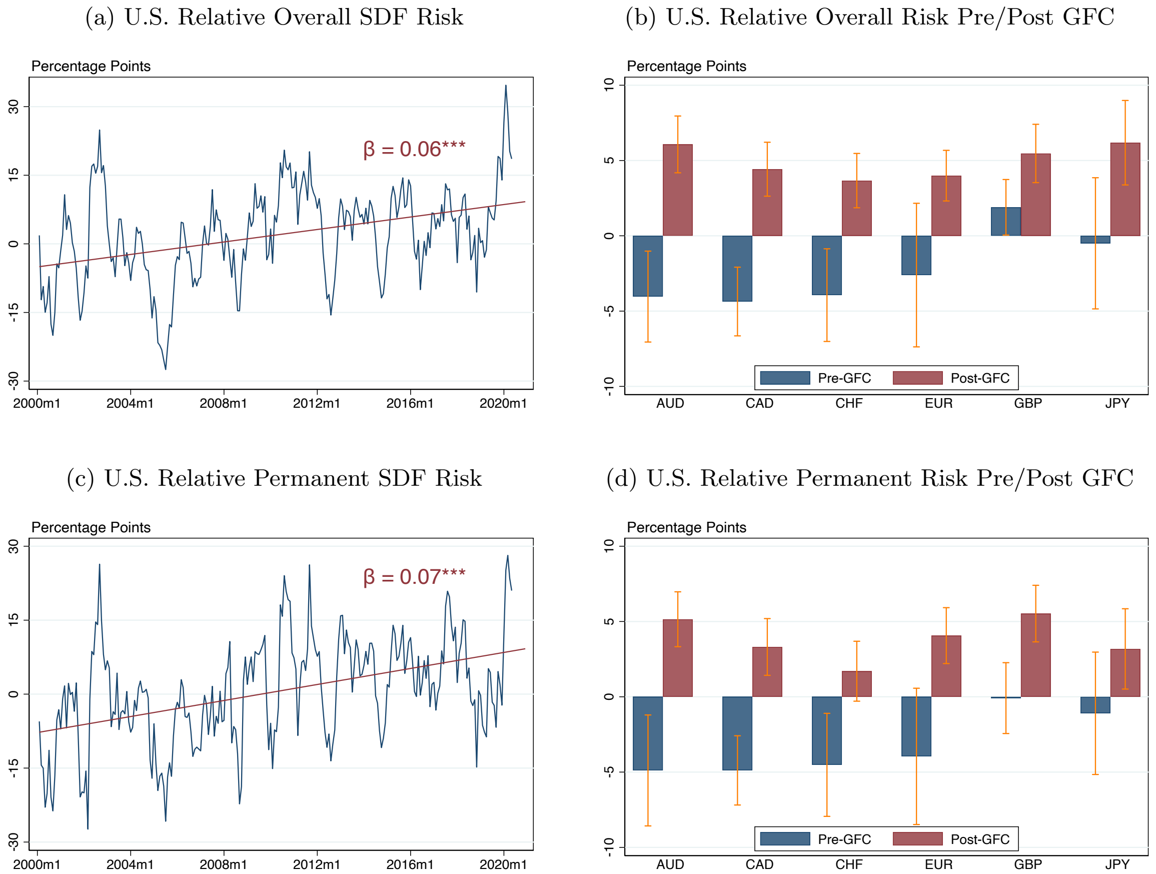
In light of the rise in U.S. permanent SDF risk over the past two decades, Figure 2 hones in

[14] For completeness, we define the *residual*, short-run conditional volatility of the SDF—the short-run risk measure—as the difference between the conditional volatility of the overall SDF and the permanent component and relate it to the bounds in expressions (7) and (9): $\widetilde{\mathcal{L}}_t\left(M^{SR}_{t+1}\right) \equiv \mathcal{L}_t\left(M_{t+1}\right) - \mathcal{L}_t\left(M^{\mathbb{P}}_{t+1}\right) \lesseqgtr \mathbb{E}_t rx^{(\infty)}_{t+1}$ where $\lesseqgtr$ highlights that $\widetilde{\mathcal{L}}_t\left(M^{SR}_{t+1}\right)$ may be greater than, less than or equal to the infinite-maturity term premium, depending on the relative deviation of $\mathcal{L}_t\left(M_{t+1}\right)$ and $\mathcal{L}_t\left(M^{\mathbb{P}}_{t+1}\right)$ from their respective bounds.

[15] This is a so-called mean-field approximation.

[16] In Appendix D, we show, as is implied by Panels 1a and 1c, that U.S. relative short-run risk is little changed over the past two decades. We also provide summary statistics for the exchange rate risk premium and the convenience yield on short-maturity Treasuries, which are little changed over the sample period as well.

Figure 1: U.S. Relative Overall and Permanent SDF Risk



(a) U.S. Relative Overall SDF Risk

(b) U.S. Relative Overall Risk Pre/Post GFC

(c) U.S. Relative Permanent SDF Risk

(d) U.S. Relative Permanent Risk Pre/Post GFC

Note. Panels 1a and 1c display the time-series of U.S. overall and permanent SDF risk from (7) and (9), respectively, relative to the corresponding unweighted average risk of G.7 currencies from 2000:M2 to 2020:M12. *** signifies that the slopes (βs) of the best-fit lines are greater than zero at the 1% significance level based on Newey and West (1987) standard errors with 4 lags. The bars in Panels 1b and 1d reflect the level of average U.S. overall and permanent SDF risk, respectively, relative to a given G.7 currency either pre- or post-GFC. The pre-GFC period ends in 2006:M12; its start is currency-specific and is dictated by the availability of convenience yield data from Du et al. (2018a). The post-GFC period is from 2007:M1 to 2020:M12. Error bars are 68% confidence intervals constructed using Newey and West (1987) standard errors with 4 lags.

on the possible channels of adjustment to changes in permanent risk across countries. Within a no-arbitrage framework with bonds and foreign exchange only, Lustig et al. (2019) show that an increase U.S. relative permanent risk should be met by an increase in the expected carry-trade returns on long-maturity bonds, $\mathbb{E}_t[rx_{t+1}^{(\infty),CT}]$ from equation (3), due either to an increase in the dollar's exchange-rate risk premium or a fall in the U.S.'s relative term premium.[17] However, contrary to this prediction, we find no evidence of an increase in U.S. long-maturity (10-year) carry-trade returns over the past two decades in either the time-series (Panel 2a) or cross-section (Panel 2b). In other words, while relative U.S. permanent risk has risen, we do not see evidence

[17] Lustig et al. (2019) argue that long-run carry trade returns are zero in expectation is indicative of no differences in permanent SDF volatility across countries.

that this has been matched or offset by changes in long-run pecuniary returns on the U.S. dollar.

While the dollar's long-run risk has remained relatively constant, the lower-left panels (Panel 2c) of Figure 2 highlight our final stylized fact: that the convenience yield on long-maturity U.S. Treasuries (i.e. the non-pecuniary return) has been significantly eroded over the past two decades.[18] This fall in Treasury convenience reflects a considerable decline in investors' perceptions as to the "specialness" of long-maturity U.S. Treasuries. In fact, prior the spike at the onset of the COVID-19 pandemic, the convenience yield on long-maturity U.S. Treasuries had become meaningfully negative, implying that investors *required* compensation to hold a U.S. Treasury in lieu of an average G.7-country bond. Importantly, about half of the total erosion in long-maturity convenience yields over the past two decades occurred *before* to the 2008 financial crisis, suggesting there may be more to this deterioration in convenience than a post-crisis expansion in Treasury supply and tightening of Primary Dealer's reserve requirements (Du et al., 2022). In what follows, we show that the long-run Treasury convenience yield provides a second potential channel of adjustment to increases in U.S. relative permanent risk.

4 Asset Pricing with Convenience Yields and Exchange Rates

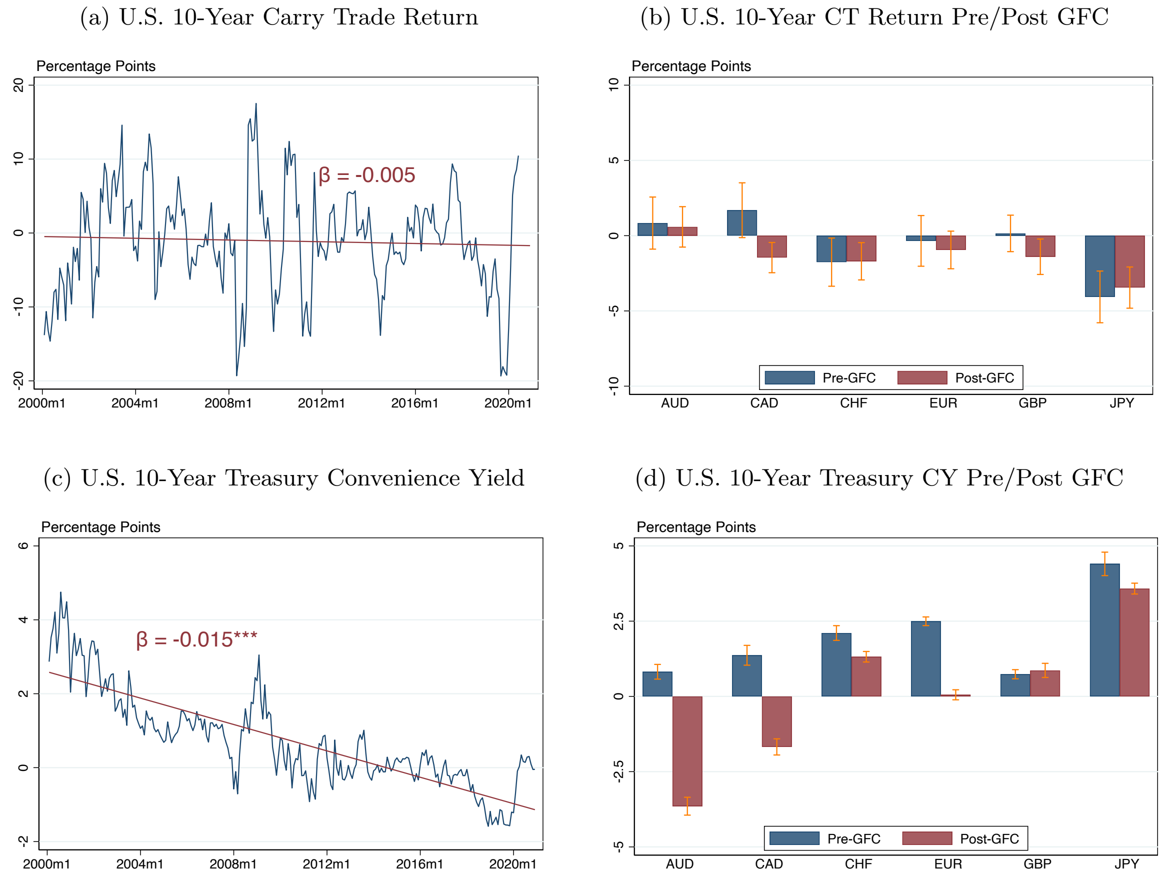
In this section, we present an asset-pricing setup to derive testable relationships between relative risk—reflected in investors' SDF volatility—exchange-rate risk premia and relative convenience yields. The approach draws on Backus et al. (2001), Engel (2014), Lustig and Verdelhan (2019), and Jiang et al. (2021a). While this specification defines a sharp theoretical baseline with which to take to the data, it leaves open the question of which shocks are responsible for fluctuations and trends in U.S. relative SDF risk, convenience yields and exchange-rate risk premia. To address this, in the next section, we highlight the prominent role of U.S. monetary policy shocks.

4.1 Asset-Market Setup

We return to the two-country, representative-agent model of asset markets introduced in Section 2. Similar to the setting in Jiang et al. (2021a), representative Home (Foreign) investors derive

[18]The erosion in U.S. Treasury convenience yields is also present in the cross-section (Panel 2d)—it holds for 5 of 6 currency pairs—although there is a fair degree of heterogeneity as to its extent. Specifically, the decline in Treasury convenience is largest relative to Australian, Canadian and Euro-area (German) government bonds and is smaller for Japanese and Swiss government bonds. Interestingly, there is little change in the relative convenience of Treasuries *vis-à-vis* U.K. Gilts. In on-going work, which we discuss in the conclusion, we explore this heterogeneity.

Figure 2: Long-Run U.S. Exchange-Rate Risk Premium and Convenience Yield



Note. Panels 2a and 2c display time series of U.S. 10-year carry trade return $rx_{t+1}^{(10Y),CT}$ from (3) and 10-year Treasury convenience yields ($\theta_{t,10Y}$) as inferred from 10-year CIP deviations (4), respectively, averaged (unweighted) across G.7 currencies from 2000:M2 to 2020:M12. *** signifies that the slope (β) of the best-fit line is less than zero at the 1% significance level based on Newey and West (1987) standard errors with 4 lags. The bars in Panels 2b and 2d reflect the level of average U.S. 10-year carry trade returns and 10-year convenience yields, respectively, for a given G.7 currency either pre- or post-GFC. The pre-GFC period ends in 2006:M12; its start is currency-specific and is dictated by the availability of convenience yield data from Du et al. (2018a). The post-GFC period is from 2007:M1 to 2020:M12. Error bars are 68% confidence intervals constructed using Newey and West (1987) standard errors with 4 lags.

both pecuniary and non-pecuniary returns from their holdings of safe assets. We define the non-pecuniary return to be a *convenience yield*, and allow this to be *both* asset- *and* investor-specific. We also allow for markets to be incomplete, as in Backus et al. (2001).

Denoting the Home (Foreign) convenience yield from holding the Home (Foreign) k-period bond at time t by $\theta_{t,k}^{H,H}$ ($\theta_{t,k}^{F,F}$), the Euler equations for Home and Foreign agents investing in their domestic k-period risk-free bonds are, respectively, given by:

$$e^{-\theta_{t,k}^{H,H}} = \mathbb{E}_t \Big[M_{t+k} R_{t,k} \Big] \tag{11}$$

$$e^{-\theta_{t,k}^{F,F}} = \mathbb{E}_t\left[M_{t+k}^* R_{t,k}^*\right] \tag{12}$$

By the same token, representative Home (Foreign) investors may derive a cross-country convenience yield, denoted by $\theta_{t,k}^{H,F}$ ($\theta_{t,k}^{F,H}$), from holding k-period bonds issued abroad. This gives rise to the following cross-country Euler equations:

$$e^{-\theta_{t,k}^{H,F}} = \mathbb{E}_t\left[M_{t+k}\frac{\mathcal{E}_{t+k}}{\mathcal{E}_t}R_{t,k}^*\right] \tag{13}$$

$$e^{-\theta_{t,k}^{F,H}} = \mathbb{E}_t\left[M_{t+k}^*\frac{\mathcal{E}_t}{\mathcal{E}_{t+k}}R_{t,k}\right] \tag{14}$$

To close the model, we conjecture an exchange-rate process that satisfies:

$$\frac{M_{t+1}^*}{M_{t+1}} = \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}e^{-\theta_{t,1}^{F,H}-\eta_{t+1}} \tag{15}$$

or, in logs, $\Delta e_{t+1} = m_{t+1}^* - m_{t+1} + \theta_{t,1}^{F,H} + \eta_{t+1}$, where η_{t+1} is an incomplete-markets stochastic wedge.[19] For the exchange-rate process in equation (15) to be unique given a similar a no-arbitrage condition for Foreign-bond Euler equations (12) and (13), it must be that $\theta_{t,1}^{F,H} = -\theta_{t,1}^{H,F}$. And, for ease of exposition, we henceforth define $\theta_{t,k} \equiv \theta_{t,k}^{F,H}$ for all k.

Finally, as in Lustig and Verdelhan (2019), one can show that the conjectured exchange-rate process in (15) satisfies the four Euler equations (11)-(14) under the following restrictions on the joint dynamics of the SDFs and the incomplete-markets wedge, which are also log-normally distributed:[20]

$$\begin{aligned}\mathbb{C}ov_t(m_{t+1}, \eta_{t,1}) &= -\mathbb{E}_t[\eta_{t,1}] + \frac{1}{2}\mathbb{V}ar_t[\eta_{t,1}]\\ \mathbb{C}ov_t(m_{t+1}^*, \eta_{t,1}) &= -\mathbb{E}_t[\eta_{t,1}] - \frac{1}{2}\mathbb{V}ar_t[\eta_{t,1}].\end{aligned} \tag{16}$$

4.2 Relative Risk, Exchange-Rate Risk Premia and Convenience Yields

Under the assumption of conditional joint log-normality of the SDFs and e^{θ}, our framework yields an expression linking the variance of the overall SDF to the exchange-rate risk premium

[19]For simplicity, we have assumed that domestic convenience yields are zero, i.e.: $\theta_{t,k}^{H,H} = \theta_{t,k}^{F,F} = 0$. The presence of domestic convenience yields considerably complicates the Alvarez and Jermann (2005) decomposition in equation (6), which we make use of in the following sub-sections.

[20]Allowing for the Home (Foreign) representative investor to hold additional Foreign (Home) assets would impose further restrictions, eventually completing financial markets. Here we assume that equity, which we use to evaluate equation (7) is only domestically traded and therefore does not complete the market.

and the relative convenience yield, which is given in the following proposition.

Proposition 1. *Given M^*_{t+1}, M_{t+1}, and an exchange-rate process in logs given by $\Delta e_{t+1} = m^*_{t+1} - m_{t+1} + \theta_{t,1} + \eta_{t+1}$, if the SDFs and $e^{\theta_{t,1}}$ are jointly conditionally log-normal, then (half) the relative SDF variance between countries is:*

$$\frac{1}{2}\mathrm{D}\mathbb{V}ar_t(m_{t+1}) = \mathbb{E}_t[rx^{FX}_{t+1}] - \theta_{t,1} - \mathbb{E}_t[\eta_{t+1}] \tag{17}$$

where $\mathrm{D}\mathbb{V}ar_t(m_{t+1}) \equiv \mathbb{V}ar_t[m_{t+1}] - \mathbb{V}ar_t[m^*_{t+1}]$ *and* $rx^{FX}_{t+1} = \log\left[\frac{R^*_{t,1}}{R_{t,1}}\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right] = r^*_{t,1} - r_{t,1} + \Delta e_{t+1}$.

Proof: See Appendix C. □

Using our measure of SDF risk in equation (7) (thus using $\mathcal{L}_t(x_{t+1})$ as our measure of conditional volatility of x_{t+1}), from equation (17) we can further derive a *preference-free* condition linking relative SDF risk, the exchange-rate risk premium, the convenience yield, and the incomplete-markets wedge. Note that, in doing so, we can relax the assumption of joint log-normality, but we retain restrictions on the joint dynamics of the SDFs and the incomplete-markets wedge similar to those in (16). Our preference-free result, the analogue to the result in Proposition 1, is presented in the following corollary.

Corollary 1. *Given M^*_{t+1}, M_{t+1}, and an exchange-rate process in logs given by $\Delta e_{t+1} = m^*_{t+1} - m_{t+1} + \theta_{t,1} + \eta_{t+1}$, then the relative SDF risk between countries is:*

$$\mathrm{D}\mathcal{L}_t(M_{t+1}) = \mathbb{E}_t[rx^{FX}_{t+1}] - \theta_{t,1} - \mathbb{E}_t[\eta_{t+1}] \tag{18}$$

where $\mathrm{D}\mathcal{L}_t(M_{t+1}) \equiv \mathcal{L}_t[M_{t+1}] - \mathcal{L}_t[M^*_{t+1}]$ *and* $rx^{FX}_{t+1} = \log\left[\frac{R^*_{t,1}}{R_{t,1}}\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right] = r^*_{t,1} - r_{t,1} + \Delta e_{t+1}$.

Proof: See Appendix C. □

This expression highlights that, for a given $\mathbb{E}_t[\eta_{t+1}]$, changes in relative risk between countries—innovations to $\mathrm{D}\mathcal{L}_t(M_{t+1})$—can generate equilibrium adjustments through two channels: the exchange-rate risk premium $\mathbb{E}_t[rx^{FX}_{t+1}]$, and the convenience yield $\theta_{t,1}$. Specifically, for given a convenience yield, a rise in U.S. (i.e. Home) SDF risk, $\mathrm{D}\mathcal{L}_t(M_{t+1}) \uparrow$, should be associated with a rise in the dollar risk premium, $\mathbb{E}_t[rx^{FX}_{t+1}] \uparrow$. Intuitively, this is because higher U.S. risk leads to an expected U.S. dollar depreciation, $\mathbb{E}_t[\Delta e_{t+1}] \uparrow$.[21] Conversely, for a given

[21] Specifically, higher U.S. risk can motivate precautionary savings and lead to a fall in U.S. interest rates, which in turn can be associated with an expected dollar depreciation and so higher expected returns to net-long positions in the foreign currency, see Fama (1984) and Lustig and Verdelhan (2007).

risk premium, higher U.S. risk decreases the return investors are willing to forego to hold U.S. Treasuries, implying a fall in the U.S. Treasury convenience yield $\theta_{t,1} \downarrow$.

4.3 Relative Permanent Risk, Long-Run FX Risk & Long-Run Convenience

To derive an expression linking permanent SDF risk to the long-run convenience yield and the long-run exchange-rate risk premium, we note that $\Lambda_t = \Lambda_t^{\mathbb{P}} \Lambda_t^{\mathbb{T}}$ implies $M_t = M_t^{\mathbb{P}} M_t^{\mathbb{T}}$ for all t, since $M_{t+1} = \Lambda_{t+1}/\Lambda_t$. Then, we rewrite equation (18) for a generic maturity k, annualizing, and taking the limit as $k \to \infty$, we find:

$$\lim_{k\to\infty} \frac{1}{k} \left\{\mathcal{L}_t[M_{t+k}] - \mathcal{L}_t[M^*_{t+k}]\right\} = \lim_{k\to\infty} \frac{1}{k}\mathbb{E}_t[rx^{FX}_{t+k}] - \lim_{k\to\infty} \frac{1}{k}\theta_{t,k} - \lim_{k\to\infty} \frac{1}{k}\mathbb{E}_t[\eta_{t+k}] \tag{19}$$

Using equation (8) and noting that $\lim_{k\to\infty} \mathbb{E}_t[rx^{(\infty)}_{t+k}] = 0$, we can rewrite this as:

$$\lim_{k\to\infty} \frac{1}{k} \left\{\mathcal{L}_t[M^{\mathbb{P}}_{t+k}] - \mathcal{L}_t[M^{\mathbb{P},*}_{t+k}]\right\} = \lim_{k\to\infty} \frac{1}{k}\mathbb{E}_t[rx^{FX}_{t+k}] - \lim_{k\to\infty} \frac{1}{k}\theta_{t,k} - \lim_{k\to\infty} \frac{1}{k}\mathbb{E}_t[\eta_{t+k}] \tag{20}$$

This expression is the analogue of Corollary 1 at long-maturities. As noted in Lustig et al. (2019), an *unconditional* relation between the volatility of the *one-period* permanent SDF and the long-run exchange-rate risk premium can be derived by taking the unconditional expectation of the above expression:

$$\mathrm{D}\mathcal{L}(M^{\mathbb{P}}_{t+1}) = \lim_{k\to\infty} \frac{1}{k}\mathbb{E}[rx^{FX}_{t+k}] - \theta_\infty - \lim_{k\to\infty} \frac{1}{k}\mathbb{E}[\eta_{t+k}], \tag{21}$$

where $\theta_\infty \equiv \lim_{k\to\infty} \frac{1}{k}\mathbb{E}[\theta_{t,k}]$.

To derive a *conditional* relation between the volatility of the *one-period* permanent SDF, the long-run convenience yield and the long-run *carry-trade* return, we combine equation (8) and expression (18) in Corollary 1, which yields the following proposition:

Proposition 2. *Under mild regularity conditions as in Alvarez and Jermann (2005), given* M^*_{t+1}, M_{t+1} *and an exchange-rate process in logs* $\Delta e_{t+1} = m^*_{t+1} - m_{t+1} + \theta_{t,1} + \eta_{t+1}$, *then relative permanent SDF risk between countries is:*

$$\begin{aligned}\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{t+1}) =& \mathbb{E}_t[rx^{FX}_{t+1}] - \mathbb{E}_t[\mathrm{D}rx^{(\infty)}_{t+1}] - \theta_{t,1} - \mathbb{E}_t[\eta_{t+1}] \\ =& \mathbb{E}_t[rx^{(\infty),CT}_{t+1}] - \theta_{t,\infty} - \theta^{slope}_t - \mathbb{E}_t[\eta_{t+1}]\end{aligned} \tag{22}$$

where $\theta_{t,\infty} \equiv \lim_{k\to\infty} \frac{1}{k}\mathbb{E}_t[\theta_{t,k}]$, $\theta_t^{slope} = \theta_{t,1} - \theta_{t,\infty}$ *and* $\mathrm{D}rx_{t+1}^{(\infty)} = rx_{t+1}^{(\infty)} - rx_{t+1}^{(\infty),*}$.

Proof: See Appendix C. □

The long-run equilibrium condition (22) highlights that, in response to movements in relative permanent risk between countries $\mathrm{D}\mathcal{L}_t(M_{t+1}^{\mathbb{P}})$, there are two channels of adjustment for a given incomplete-markets wedge: (i) the relative convenience yield on long-maturity Treasuries $\theta_{t,\infty}$, controlling for the slope of the relative convenience yield curve θ_t^{slope}; and (ii) the exchange-rate risk premium $\mathbb{E}_t[rx_{t+1}^{FX}]$, controlling for the relative yield curve slope $\mathbb{E}_t[\mathrm{D}rx_{t+1}^{(\infty)}]$.

5 Empirical Results

In this section, we take our model to the data in 3 stages. First, in 5.1, we test the asset pricing relations implied by Corollary 1 and Proposition 2 using contemporaneous panel regressions. Second, in 5.2, we turn to a dynamic, structural analysis of innovations to U.S. relative risk by testing Corollary 1 and Proposition 2 in a panel-VAR setting. And third, in 5.3, we study the joint dynamic responses of U.S. relative permanent risk, long-run Treasury convenience and long-run dollar risk premia to high-frequency-identified monetary policy shocks.

5.1 Static Relation: Treasury Convenience, Dollar Premia and U.S. Risk

We begin estimating equation (18) from Corollary 1 in order to gain insight on the equilibrium adjustment to innovation in relative U.S. risk. We do so in two ways. First, we assess the association between the convenience yield on short-maturity Treasuries relative to country i's government bonds, $\theta_{i,t,1}$, and the U.S.'s overall SDF risk relative to country i's, $\mathrm{D}\mathcal{L}_t(M_{i,t+1})$, controlling for the dollar's exchange-rate risk premium *vis-à-vis* currency i, $rx_{i,t+1}^{FX}$:[22]

$$\theta_{i,t,1} = \beta_0 + \beta_1 \mathrm{D}\mathcal{L}_t(M_{i,t+1}) + \beta_2 rx_{i,t+1}^{FX} + f_i + \varepsilon_{i,t} \tag{23}$$

where f_i denote country fixed effects. Second, we assess the link between the exchange-rate risk premium and U.S. relative total risk, controlling for the convenience yield:

$$rx_{i,t+1}^{FX} = \gamma_0 + \gamma_1 \mathrm{D}\mathcal{L}_t(M_{i,t+1}) + \gamma_2 \theta_{i,t,1} + f_i + \varepsilon_{i,t} \tag{24}$$

[22]Throughout this section and the subsequent ones, since the incomplete-markets wedge enters our asset pricing conditions *ex-ante* ($\mathbb{E}_t[\eta_{t+1,k}]$) we treat it as unobservable, assume that it has zero mean, and that it is uncorrelated with the regressors in our empirical analysis.

The estimated coefficients are displayed Table 1a, alongside, as for all our regressions in this section, Driscoll and Kraay (1998) standard errors, which correct for heteroskedasticity, serial correlation and cross-equation correlation. Consistent with Corollary 1, we find a positive relationship between U.S. relative total risk and the dollar's (short-run) exchange rate risk premium, reflecting the dollar's tendency to depreciate when U.S. risk rises. The magnitude of the coefficient, which is unaltered when controlling for short-maturity Treasury convenience, implies that a 1 percentage point increase in U.S. risk (equity returns) vis-à-vis G.7 countries is associated with about a 0.14 percentage point increase in the dollar's risk premium. Interestingly, in Table D.1b in Appendix D, we find that the exchange-rate risk premium is significantly more-associated with transitory rather than permanent U.S. risk.

The negative association between U.S. relative risk and the convenience yield on short-maturity U.S. Treasuries, while also consistent with Corollary 1, is much less significant.[23] The magnitude, when controlling for the dollar risk premium, implies that a 1 percentage point rise in relative U.S. risk (equity returns) is associated with a less than 0.01 percentage point fall in the convenience of short-maturity Treasuries. This effect is small relative to the relation between U.S. relative risk and dollar risk, even accounting for the fact that convenience yields tend to be an order of magnitude smaller than the exchange rate risk premium. In all, our findings imply that the dollar exchange rate risk premium is the primary contemporaneous channel of adjustment to changes in U.S. relative SDF risk, with most of this adjustment coming in response to U.S. transitory risk.

Next, we investigate the contemporaneous adjustment of the long-run convenience yield on U.S. Treasuries, $\theta_{i,t,\infty}$, and the dollar's long-run carry trade returns, $rx_{i,t+1}^{(\infty),CT}$, to U.S. relative permanent risk, $\mathrm{D}\mathcal{L}_t(M_{i,t+1}^{\mathbb{P}}$, by testing equation (22) from Proposition 2. We again do so in two ways:

$$\theta_{i,t,\infty} = \beta_0 + \beta_1 \mathrm{D}\mathcal{L}_t(M_{i,t+1}^{\mathbb{P}}) + \beta_2 rx_{i,t+1}^{(\infty),CT} + \beta_3 \theta_{i,t}^{slope} + f_i + \varepsilon_{i,t} \tag{25}$$

$$rx_{i,t+1}^{(\infty),CT} = \gamma_0 + \gamma_1 \mathrm{D}\mathcal{L}_t(M_{i,t+1}^{\mathbb{P}}) + \gamma_2 \theta_{i,t,\infty} + \gamma_3 \theta_{i,t}^{slope} + f_i + \varepsilon_{i,t} \tag{26}$$

The results are displayed in Table 1b.[24] Similar to the total risk case, there is a significant association between U.S. permanent risk and the dollar carry trade return fashioned using long-maturity bonds. Importantly, as is again shown in Table D.1b, much of the adjustment of

[23]In Table D.1a in Appendix D, we show that this response in short-maturity convenience to U.S. relative risk is driven primarily by a response to its permanent component.

[24]In our baseline, motivated by the unconditional equilibrium relation derived in equation (21), along with the collinearity between $\theta_{i,t,\infty}$ and $\theta_{i,t}^{slope}$, we restrict β_2 and γ_2 to be zero. In Appendix D.3, we show the contemporaneous effects of U.S. permanent risk are similar without this restriction. Further, we show the effects of U.S. relative permanent risk on the convenience yield curve slope are mixed.

Table 1: Contemporaneous Channels of Adjustment to U.S. Relative Risk

(a) U.S. Relative Total Risk

	(1)	(2)	(3)	(4)
Vars	$\theta_{i,t,1}$	$rx^{FX}_{i,t+1}$	$\theta_{i,t,1}$	$rx^{FX}_{i,t+1}$
$\mathrm{D}\mathcal{L}_t(M_{i,t+1})$	-.006	.139***	-.007*	.141***
	(.004)	(.029)	(.004)	(.029)
Controls	No	No	Yes	Yes
Observations	1551	1551	1551	1551
Within R^2	0.01	0.09	0.01	0.09

(b) U.S. Relative Permanent Risk

	(1)	(2)	(3)	(4)
Vars	$\theta_{i,t,\infty}$	$rx^{(\infty),CT}_{i,t+1}$	$\theta_{i,t,\infty}$	$rx^{(\infty),CT}_{i,t+1}$
$\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1})$	-.024***	.200***	-.032***	.219***
	(.006)	(.028)	(.005)	(.029)
Controls	No	No	Yes	Yes
Observations	1597	1597	1597	1597
Within R^2	0.05	0.15	0.08	0.17

Note. Table 1 presents the coefficient estimates from the Corollary 1 regressions (23) and (24) in Table 1a and from the Proposition 2 regressions (25) and (26) in Table 1b. The panel regressions are estimated for six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD in an unbalanced sample from 1997:M1–2020:M12 with currency fixed effects. *, **, and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively, using Driscoll and Kraay (1998) standard errors (reported in parentheses).

$rx^{(\infty),CT}_{i,t+1}$ comes from the response of the relative term premium component, rather than from pure dollar risk. Unlike the total-risk case, the convenience yield on long-maturity U.S. Treasuries serves as a second contemporaneous channel of adjustment to changes in U.S. permanent risk. Quantitatively, a 1 percentage point increase in relative U.S. permanent risk (equity net term premium) is associated with a greater than 0.03 percentage point fall in the convenience yield on long-maturity Treasuries, more than twice the average monthly decline in long-run convenience yields over our sample (see Figure 2c).

5.2 Dynamic Relation: Treasury Convenience, Dollar Premia and U.S. Risk

In this section, we turn to a structural analysis of innovations to relative U.S. (permanent) risk, testing Corollary 1 and Proposition 2 of our model dynamically using a Cholesky-identified panel VAR.

The VAR includes three variables, in addition to country fixed effects: (i) a measure of relative U.S. risk—either total $\mathrm{D}\mathcal{L}_t(M_{i,t+1})$ or permanent $\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1})$, measured using combinations of equity and term premia; (ii) a measure of the convenience yield—either on short-maturity $\theta_{i,t,1}$ or long-maturity $\theta_{i,t,\infty}$ Treasuries; and (iii) a measure of dollar risk—either the exchange-rate risk premium $rx^{FX}_{i,t+1}$ or the one-period carry-trade return from long-term bonds

$rx^{(\infty),CT}_{i,t+1}$.[25] Throughout, our baseline ordering of the variables is: first, the measure of relative U.S. risk, which by virtue of the U.S.'s size and importance in the global financial system, we view as being contemporaneously unaffected by developments in currency markets; second, the convenience yield measure; and third, the dollar premium measure, which we let react to both convenience yields and relative risk contemporaneously. While the ordering of the latter two variable is the same as in Jiang et al. (2021a), our results are robust to alternative orderings. Our key innovation is to consider the role of shocks to U.S. relative risk.

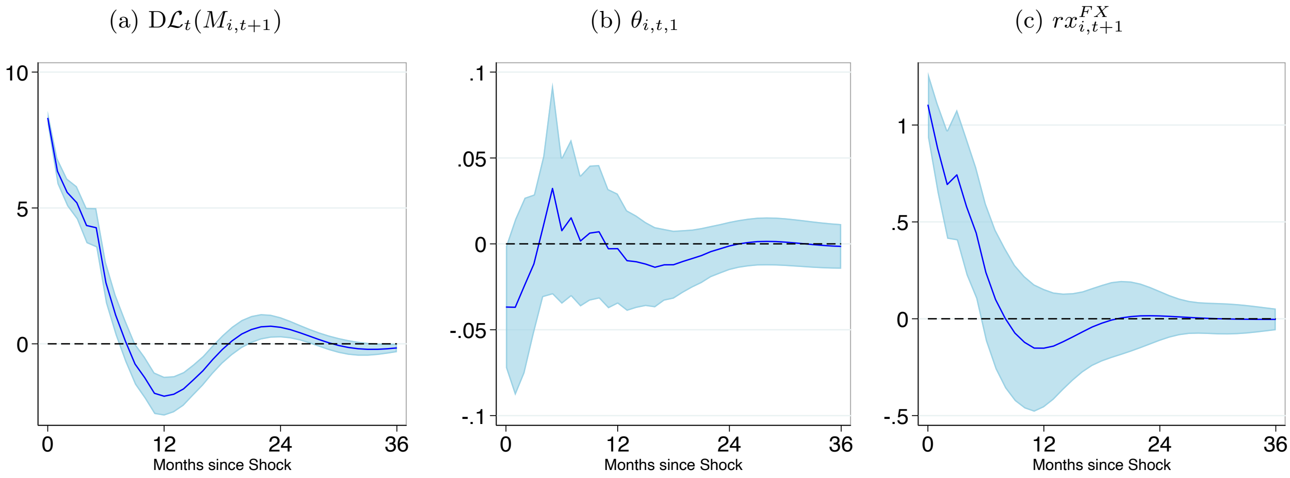
We begin by testing Corollary 1. Specifically, we study the dynamic response of short-maturity convenience yields and the dollar risk premium to a one (half) standard deviation rise in U.S. total risk vis-à-vis G.7 countries, which corresponds to about an 8 percentage point rise in relative U.S. equity excess returns. The results are displayed in Figure 3 and are generally consistent with the contemporaneous regressions in Table 1a. On the one hand, a rise in U.S. total risk induces a significant increase the dollar risk premium on impact, but this effect dissipates within 6 months. On the other, while the response of short-maturity convenience yields has the correct sign on-impact, the effect is significant only in the first month. In all, our structural analysis again suggests that most of the adjustment to U.S. relative total risk operates through pecuniary rather than non-pecuniary returns.

Furthermore, in Appendix D.2, we decompose U.S. relative total risk into its permanent and transitory components and study their distinct effects on the exchange rate risk premium and the short-maturity convenience yield. We uncover a couple of interesting results that refine our understanding of the transmission of U.S. relative risk. First, by comparing the impulse responses in Figures D.2 and D.3, consistent with our contemporaneous regression results, we find the exchange rate risk premium responds more to innovations in U.S. transitory risk than in U.S. permanent risk. Second, we find that non-responsiveness of short-maturity convenience yields to U.S. total risk arises because of the offsetting effects permanent and transitory innovations. In particular, while a rise in U.S. permanent risk induces a fall in short-maturity Treasury convenience, suggesting they are well-anchored to relative risk fundamentals, a rise in U.S. short-run risk actually leads to an increase in short-run convenience. Greater transitory risk, therefore, does not compromise the implicit seignorage the U.S. earns on its issuance of short-maturity government debt, a reflection of its safe-haven status.

Next, we turn to test Proposition 2. Unlike the total risk relationship, Figure 4 highlights

[25] In our baseline permanent-risk VAR, motivated by the unconditional equilibrium relation in (21) and to avoid collinearity, we include the convenience-yield slope $\theta^{slope}_{i,t}$ as an exogenous control. As shown in Appendix D.3, our results are robust to including $\theta^{slope}_{i,t}$ as an endogenous variable.

Figure 3: Response of Convenience Yields and Dollar Premia to U.S. Relative Risk Shocks



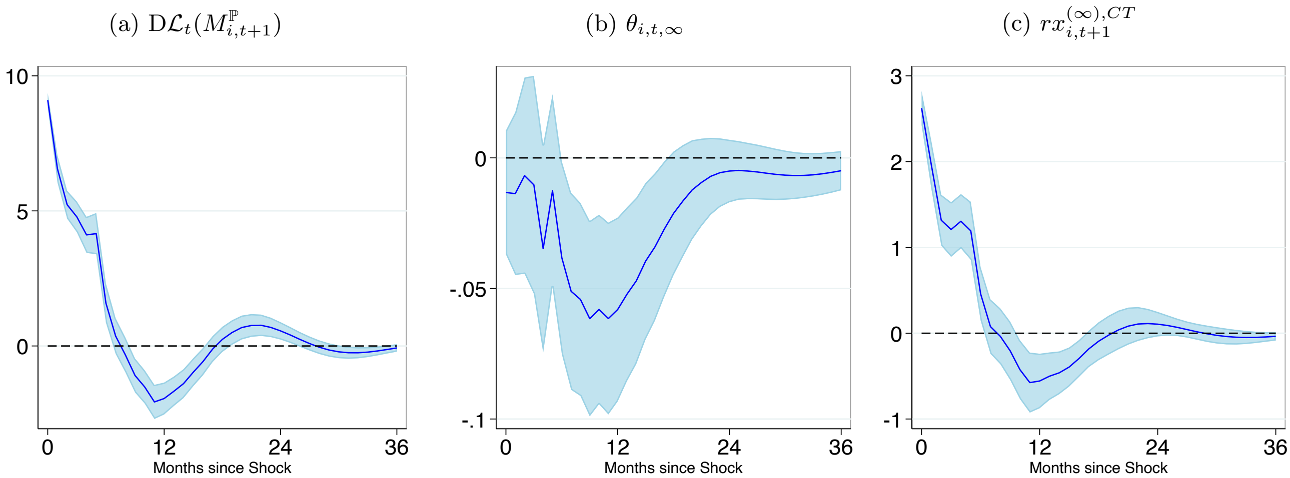
Note. Figure 3 presents the impulse response functions to a 1/2 standard deviation shock to U.S. relative risk $\mathrm{D}\mathcal{L}_t(M_{i,t+1})$ (panel 3a) for short-maturity U.S. convenience yields (panel 3b) and dollar risk premia (panel 3c) from a panel VAR(6) containing six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points. The ordering is $[\mathrm{D}\mathcal{L}_t(M_{i,t+1}), \theta_{i,t,1}, rx^{FX}_{i,t+1}]$.

that in response to a rise in U.S. relative permanent risk, there is a significant adjustment in both the long-run convenience of U.S. Treasuries (Panel 4b) and in the long-run carry trade return (Panel 4c). The direction of these adjustments is consistent with the predictions of our model. A key distinction between the two channels of adjustment is their degree of persistence. As in the total-risk case, long-run dollar carry trade returns on impact to a rise in U.S. permanent risk, but return to zero within 6 months.[26] Conversely, the decline in the long-run convenience of U.S. Treasuries builds up over time, reaching a peak response at 9 months, and remains different from zero up to 18 months after the shock. Quantitatively, a one standard deviation rise in U.S. permanent risk leads to a peak-decline in the convenience yield on long-maturity Treasuries of more than 0.06 percentage points, about three-times the average monthly decline over our sample. This suggests that the rise in U.S. relative permanent risk and the fall in the convenience of long-maturity Treasuries may be two sides of the same coin.

Finally, we highlight that our long-run equilibrium relation in Proposition 2 is general, and not tied to a specific time period. To illustrate this, we re-estimate our Proposition 2 VAR both pre- and post-GFC. The results are displayed in Figure 5 and demonstrate the temporal-stability of the equilibrium relationship between U.S. relative premanent risk, the convenience

[26]Importantly, as in the contemporaneous case, about two thirds of the response in long-run carry trade returns to permanent risk innovations is due to an adjustment in short-run U.S. relative risk, with the remaining third coming from the pure dollar exchange rate risk premium (Figure D.2). Thus, as stressed earlier, transitory risk is the primary driver of changes in dollar risk in our setup.

Figure 4: U.S. Relative Permanent Risk Shocks on Long-Run Convenience and Dollar Premia



Note. Figure 4 presents the impulse response functions to a 1/2 standard deviation shock to U.S. relative risk $\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1})$ (panel 4a) for long-maturity U.S. convenience yields (panel 4b) and long-run dollar carry trade returns (panel 4c) from a panel VAR(6) containing six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points. The ordering is $[\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1}), \theta_{i,t,\infty}, rx^{(\infty),CT}_{i,t+1}]$.

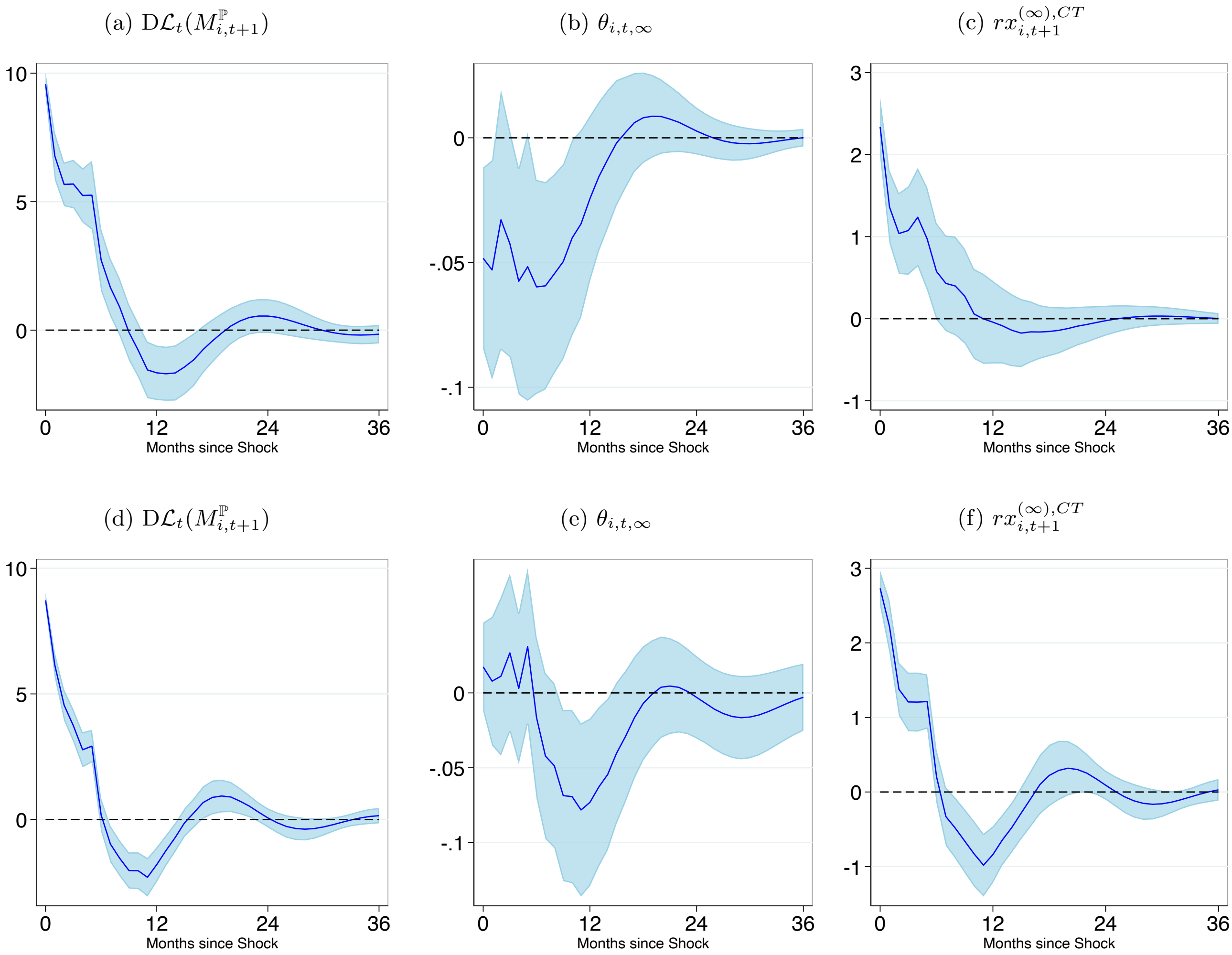
yield on long-maturity Treasuries and the dollar's long-run carry trade return. This stability is encouraging since the trend rise in U.S. relative permanent risk (Figure 1) and decline in long-run convenience yields (Figure 2) straddles both regimes. Still, our results from this section leave open the underlying driver of these two trends, which we address in the following section.

5.3 Monetary Policy & Long-Run U.S. Risk, Dollar Premia and Convenience

While we have documented, in particular, the significant adjustment of long-maturity U.S. Treasury convenience yields to increases in U.S. relative permanent risk, our results thus far have been are silent as to the underlying driver of the observed increase in U.S. risk and fall in Treasury convenience over the previous two decades. In this section, we investigate whether easy U.S. monetary policy, both pre-GFC during the so-called "Greenspan put" period as well as in the post-GFC monetary environment dominated by the zero-lower-bound on interest rates and Federal Reserve asset purchase programs, may have contributed to the observed trends in U.S. permanent risk and Treasury convenience.

To test this, in our baseline, we augment the permanent-risk VAR we used to test Proposition 2 with the Bu et al. (2021) monetary policy shock series, ordered first. These monetary policy shocks, which we denote by ε^m_t, are constructed from high-frequency interest-rate move-

Figure 5: Effects of U.S. Relative Permanent Risk Shocks Pre- & Post-GFC

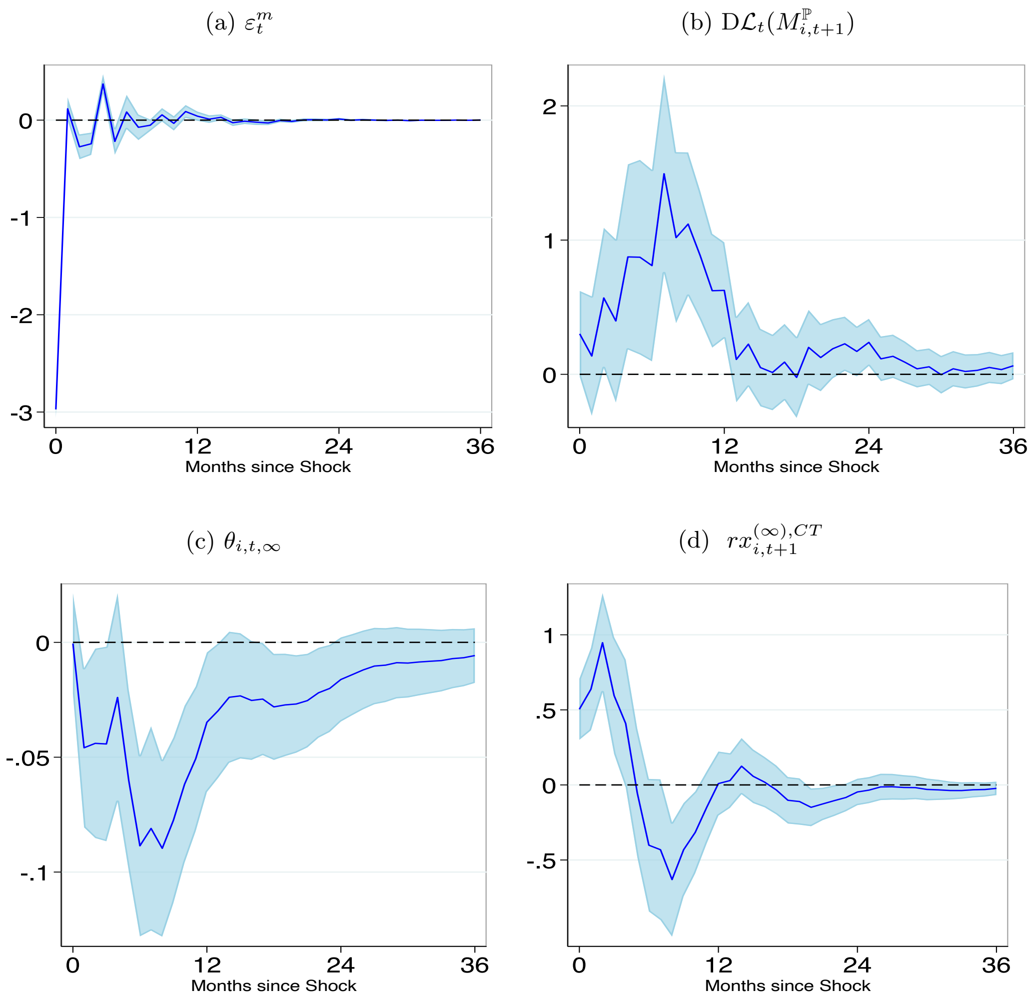


Note. Figure 5 presents the impulse response functions to a 1/2 standard deviation shock to U.S. relative risk for long-maturity U.S. convenience yields and long-run dollar carry trade returns over 2 different sample periods. The Pre-GFC sample (Panels 5a, 5b and 5c) is unbalanced from 1997:M1–2006:M12; The Post-GFC sample (Panels 5d, 5e and 5f) is from 2007:M1–2020:M12. In both cases, the impulses are from a panel VAR(6) with six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points. The ordering in both cases is $[\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1}), \theta_{i,t,\infty}, rx^{(\infty),CT}_{i,t+1}]$.

ments along the entire U.S. Treasury yield curve and so provide a unified measure of both conventional and unconventional U.S. monetary policy surprises. These shocks are also appealing since the authors' show they are devoid of the central bank information effect and cannot be predicted from the data available prior to shock's realization. In what follows, we also investigate the transmission of conventional and unconventional monetary policy shocks separately using the Swanson (2021) shock series.

Our baseline results are displayed in Figure 6 and highlight that a shock U.S. monetary

Figure 6: Transmission of U.S. Monetary Policy Shocks to U.S. Relative Permanent Risk, Long-Run Convenience Yields and Long-Run Dollar Premia



Note. Figure 6 presents the impulse response functions to a 1 standard deviation monetary policy easing shock (panel 6a) for U.S. relative permanent risk (panel 6b), long-maturity U.S. convenience yields (panel 6c) and long-run dollar carry trade returns (panel 6d) from a panel VAR(7) with six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points, except for ε_t^m, which is in basis points. The ordering is $[\varepsilon_t^m, \mathrm{D}\mathcal{L}_t(M_{i,t+1}^{\mathbb{P}}), \theta_{i,t,\infty}, rx_{i,t+1}^{(\infty),CT}]$.

policy easing, $\varepsilon_t^m \downarrow$, induces a considerable increase in U.S. relative permanent risk as well as a significant fall in the long-maturity Treasury convenience yield. Long-maturity dollar carry trade returns, on the other hand, rise on-impact—which may reflect a dollar depreciation—before overshooting and becoming negative. Strikingly, the responses of U.S. risk and Treasury convenience mirror each other: they both peak at 9 months and have moments of significance up to 2 years after the initial shock. Quantitatively, their magnitudes imply that a 1 standard deviation (3 basis point) U.S. monetary easing leads to a peak-increase in U.S. relative risk of 1.5

percentage points and a peak-decline in long-maturity Treasury convenience of 0.08 percentage points, both of which are economically significant. In all, our results are consistent with easy U.S. monetary policy over the past two decades playing a role in the rise in U.S. permanent risk and a decline in the "specialness", and seignorage on, long-maturity U.S. Treasuries.

Finally, to compare the impact of conventional and unconventional monetary policy, we re-estimate our monetary-policy VAR using distinct interest rate, forward guidance and asset purchase shocks. While interest rate shocks are most-common before the GFC and asset purchase shocks present only after 2008, unconventional forward guidance surprises straddle both time periods. The results are displayed in Figure 7 and highlight that, for each type of shock, monetary policy easings induce a rise in U.S. permanent risk and fall in Treasury convenience. Interestingly, this relationship is strongest for unconventional policy, suggesting that these unorthodox methods of stimulating the economy may have harmful side-effects for the preeminence of U.S. Treasuries as the safe-haven asset of the financial system and encourage a decline in investors' perceptions as to the long-run safety of the U.S. relative to other advanced economies.

6 Conclusion

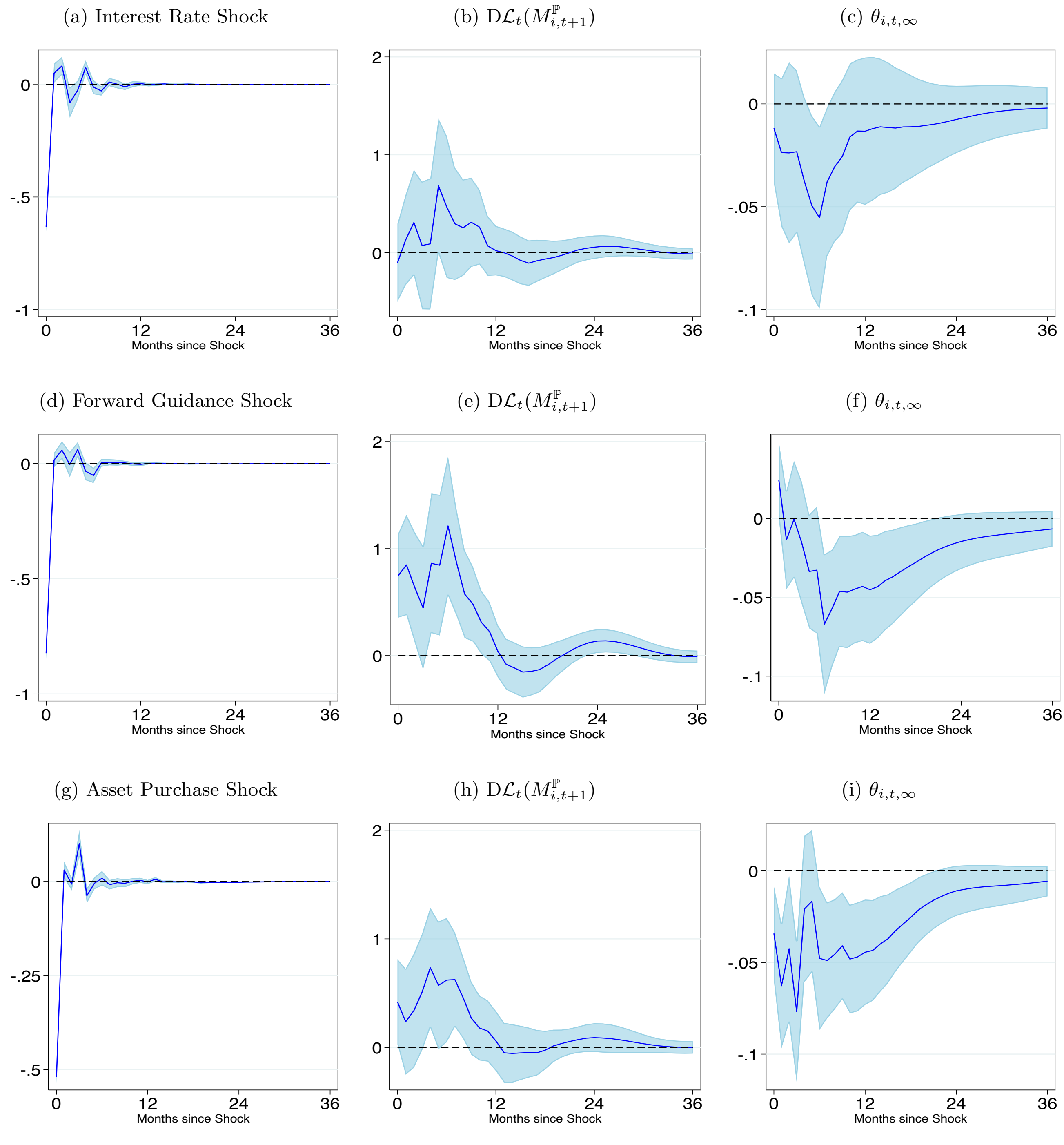
In this paper, we have documented that, over the past two decades, the U.S. has become relatively riskier *vis-à-vis* a panel of advanced (G.7) countries, driven by a rise in permanent risk. At the same time, long-term carry trade returns have not deteriorated commensurately. Instead, the long-run convenience yield on U.S. Treasuries has been eroded.

We have reconciled these findings within a no-arbitrage framework, deriving a link between exchange-rate risk premia, bond premia, equity premia and convenience yields. We have done so by characterising their relationship to transitory and permanent shocks to investors' SDFs, noting that innovations to these two sources of risk elicit distinct responses from exchange rates and convenience yields.

Most notably, we find that a rise in U.S. permanent risk induces a significant and persistent decline in long-maturity Treasury convenience yields. This relation between long-run risk and non-pecuniary returns holds both before and after the GFC and suggests that the rise in U.S. permanent risk and the fall in long-maturity U.S. convenience yields are two sides of the same coin.

Conversely, at short-maturities, U.S. convenience yields actually rise when U.S. transitory

Figure 7: Transmission of U.S. Interest Rate, Forward Guidance and Asset Purchase Shocks



Note. Figure 7 presents the impulse response functions, from separate VARs, to 1 standard deviation expansionary interest rate shocks (Panels 7a, 7b, 7c), forward guidance shocks (Panels 7d, 7e, 7f), and asset purchase shocks (Panels 7g, 7h, 7i), respectively, for U.S. relative permanent risk, long-maturity U.S. convenience yields and long-run dollar carry trade returns, whose responses are reported in Figure D.6 in Appendix D due to space constraints. The IRFs are from a panel VAR(6) with six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points, except for ε^m_t, which is in basis points. The ordering is $[\varepsilon^m_t, \mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1}), \theta_{i,t,\infty}, rx^{(\infty),CT}_{i,t+1}]$.

risk increases, which arguably reflects investors' perception of U.S. (dollar) assets as safe assets. Further, we find that pecuniary dollar returns primarily respond to innovations to transitory rather than permanent risk.

Finally, we showed that expansionary U.S. monetary policy, especially from unconventional tools such as forward guidance and asset purchases, has contributed to the rise in U.S. long-run risk and a fall in the convenience of long-maturity Treasuries. In on-going work, we look to explain cross-country differences in the rise in permanent risk and fall in convenience yields using cross-sectional differences in country's monetary stance. Anecdotally, the U.K. and Japan, who saw relatively mild increases in long-run risk and falls in convenience yields, also engaged in large amounts of quantitative easing whereas Australia and Canada, whose movements in risk and convenience yields were more stark, used uncoventional tools to a far lesser extent.

References

Alvarez, F. and U. J. Jermann (2005): "Using asset prices to measure the persistence of the marginal utility of wealth," *Econometrica*, 73, 1977–2016.

Anderson, N. and J. Sleath (2001): "New estimates of the UK real and nominal yield curves," Bank of England Staff Working Papers, Bank of England.

Atkeson, A., J. Heathcote, and F. Perri (2022): "The end of privilege: A reexamination of the net foreign asset position of the United States," Tech. rep., National Bureau of Economic Research.

Augustin, P., M. Chernov, L. Schmid, and D. Song (2020): "The term structure of CIP violations," Tech. rep., National Bureau of Economic Research.

Backus, D. K., S. Foresi, and C. I. Telmer (2001): "Affine term structure models and the forward premium anomaly," *The Journal of Finance*, 56, 279–304.

Bernanke, B. (2005): "The global saving glut and the US current account deficit," Tech. rep., Board of Governors of the Federal Reserve System (US).

Bruno, V. and H. S. Shin (2015): "Cross-border banking and global liquidity," *The Review of Economic Studies*, 82, 535–564.

Bu, C., J. Rogers, and W. Wu (2021): "A unified measure of Fed monetary policy shocks," *Journal of Monetary Economics*, 118, 331–349.

Caballero, R. J., E. Farhi, and P.-O. Gourinchas (2008): "An Equilibrium Model of "Global Imbalances" and Low Interest Rates," *American Economic Review*, 98, 358–393.

Campbell, J. Y. and J. Ammer (1993): "What moves the stock and bond markets? A variance decomposition for long-term asset returns," *The journal of finance*, 48, 3–37.

Campbell, J. Y., C. Pflueger, and L. M. Viceira (2020): "Macroeconomic drivers of bond and equity risks," *Journal of Political Economy*, 128, 3148–3185.

Colacito, R. and M. M. Croce (2011): "Risks for the long run and the real exchange rate," *Journal of Political economy*, 119, 153–181.

Driscoll, J. C. and A. C. Kraay (1998): "Consistent covariance matrix estimation with spatially dependent panel data," *Review of Economics and Statistics*, 80, 549–560.

Du, W., B. M. Hébert, and W. Li (2022): "Intermediary balance sheets and the treasury yield curve," Tech. rep., National Bureau of Economic Research.

Du, W., J. Im, and J. Schreger (2018a): "The U.S. Treasury Premium," *Journal of International Economics*, 112, 167–181.

Du, W., A. Tepper, and A. Verdelhan (2018b): "Deviations from covered interest rate parity," *The Journal of Finance*, 73, 915–957.

Eichengreen, B., R. Hausmann, and U. Panizza (2007): "Currency mismatches, debt intolerance, and the original sin: Why they are not the same and why it matters," in *Capital controls and capital flows in emerging economies: Policies, practices, and consequences*, University of Chicago Press, 121–170.

Engel, C. (2014): "Exchange Rates and Interest Parity," Elsevier, vol. 4, chap. Chapter 8, 453–522.

——— (2016): "Exchange Rates, Interest Rates, and the Risk Premium," *American Economic Review*, 106, 436–474.

Engel, C. and S. P. Y. Wu (2018): "Liquidity and Exchange Rates: An Empirical Investigation," NBER Working Papers 25397, National Bureau of Economic Research, Inc.

Fama, E. F. (1984): "Forward and spot exchange rates," *Journal of Monetary Economics*, 14, 319–338.

Farhi, E. and X. Gabaix (2016): "Rare disasters and exchange rates," *The Quarterly Journal of Economics*, 131, 1–52.

Farhi, E. and F. Gourio (2018): "Accounting for macro-finance trends: Market power, intangibles, and risk premia," Tech. rep., National Bureau of Economic Research.

Farhi, E. and M. Maggiori (2018): "A model of the international monetary system," *The Quarterly Journal of Economics*, 133, 295–355.

Gabaix, X. and M. Maggiori (2015): "International Liquidity and Exchange Rate Dynamics," *The Quarterly Journal of Economics*, 130, 1369–1420.

Gopinath, G., E. Boz, C. Casas, F. J. Díez, P.-O. Gourinchas, and M. Plagborg-Møller (2020): "Dominant currency paradigm," *American Economic Review*, 110, 677–719.

Gourinchas, P.-O. (2021): "International Macroeconomics: From the Global Financial Crisis to COVID-19, and Beyond," Tech. rep., IMF Mundell-Flemming Lecture.

Gourinchas, P.-O., W. D. Ray, and D. Vayanos (2022): "A Preferred-Habitat Model of Term Premia, Exchange Rates, and Monetary Policy Spillovers," Tech. rep., National Bureau of Economic Research.

Gourinchas, P.-O. and H. Rey (2007): "International financial adjustment," *Journal of Political Economy*, 115, 665–703.

Gourinchas, P.-O., H. Rey, and N. Govillot (2010): "Exorbitant Privilege and Exorbitant Duty," IMES Discussion Paper Series 10-E-20, Institute for Monetary and Economic Studies, Bank of Japan.

Gürkaynak, R. S., B. Sack, and J. H. Wright (2007): "The US Treasury yield curve: 1961 to the present," *Journal of monetary Economics*, 54, 2291–2304.

Itskhoki, O. and D. Mukhin (2021): "Exchange rate disconnect in general equilibrium," *Journal of Political Economy*, 129, 2183–2232.

Jeanne, O. and A. K. Rose (2002): "Noise trading and exchange rate regimes," *The Quarterly Journal of Economics*, 117, 537–569.

Jiang, Z., A. Krishnamurthy, and H. Lustig (2020): "Dollar Safety and the Global Financial Cycle," NBER Working Papers 27682, National Bureau of Economic Research, Inc.

——— (2021a): "Foreign safe asset demand and the dollar exchange rate," *The Journal of Finance*, 76, 1049–1089.

Jiang, Z., A. Krishnamurthy, and H. N. Lustig (2021b): "Beyond incomplete spanning: Convenience yields and exchange rate disconnect," *Available at SSRN 3852298*.

Kekre, R. and M. Lenel (2021): "The flight to safety and international risk sharing," Tech. rep., National Bureau of Economic Research.

Krishnamurthy, A. and H. N. Lustig (2019): "Mind the gap in sovereign debt markets: The US Treasury basis and the dollar risk factor," in *2019 Jackson Hole Economic Symposium, Stanford University Graduate School of Business Research Paper*, 3443231.

Krishnamurthy, A. and A. Vissing-Jorgensen (2012): "The aggregate demand for treasury debt," *Journal of Political Economy*, 120, 233–267.

Liao, G. and T. Zhang (2020): "The Hedging Channel of Exchange Rate Determination," International Finance Discussion Papers 1283, Board of Governors of the Federal Reserve System (U.S.).

Lilley, A., M. Maggiori, B. Neiman, and J. Schreger (2019): "Exchange Rate Reconnect," NBER Working Papers 26046, National Bureau of Economic Research, Inc.

Liu, Y., L. Schmid, and A. Yaron (2020): "The risks of safe assets," *Available at SSRN 3699618*.

Lloyd, S. and E. Marin (2020): "Exchange rate risk and business cycles," Bank of England Staff Working Papers 872, Bank of England.

Lustig, H., A. Stathopoulos, and A. Verdelhan (2019): "The term structure of currency carry trade risk premia," *American Economic Review*, 109, 4142–77.

Lustig, H. and A. Verdelhan (2007): "The cross section of foreign currency risk premia and consumption growth risk," *American Economic Review*, 97, 89–117.

——— (2019): "Does incomplete spanning in international financial markets help to explain exchange rates?" *American Economic Review*, 109, 2208–44.

Maggiori, M. (2017): "Financial intermediation, international risk sharing, and reserve currencies," *American Economic Review*, 107, 3038–71.

Meese, R. A. and K. Rogoff (1983): "Empirical exchange rate models of the seventies: Do they fit out of sample?" *Journal of International Economics*, 14, 3–24.

Miranda-Agrippino, S. and H. Rey (2020): "US monetary policy and the global financial cycle," *The Review of Economic Studies*, 87, 2754–2776.

Newey, W. and K. West (1987): "A Simple, Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix," *Econometrica*, 55, 703–08.

Obstfeld, M. and K. Rogoff (2000): "The six major puzzles in international macroeconomics: is there a common cause?" *NBER macroeconomics annual*, 15, 339–390.

Ostry, D. A. (2022): "Tails of Foreign Exchange at Risk (FEaR)," *Unpublished Manuscript*.

Rey, H. (2015): "Dilemma not Trilemma: The Global Financial Cycle and Monetary Policy Independence," NBER Working Papers 21162, National Bureau of Economic Research, Inc.

Swanson, E. T. (2021): "Measuring the effects of federal reserve forward guidance and asset purchases on financial markets," *Journal of Monetary Economics*, 118, 32–53.

Theil, H. (1967): "Economics and information theory," Tech. rep.

Valchev, R. (2020): "Bond convenience yields and exchange rate dynamics," *American Economic Journal: Macroeconomics*, 12, 124–66.

Wright, J. (2011): "Term Premia and Inflation Uncertainty: Empirical Evidence from an International Panel Dataset," *American Economic Review*, 101, 1514–34.

Appendix

A Data Sources

We use convenience yields at 3-month, 1-year and 10-year maturities from Du, Im, and Schreger (2018a) for 6 industrialised countries relative to the U.S.: Australia, Canada, euro area, Japan, Switzerland and U.K. Our benchmark sample begins 1997:01, although the panel is unbalanced as convenience yields are not available from the start of the sample in all jurisdictions. We use the 3-month and 1-year convenience yields to construct 6-month convenience yields by linearly interpolating according to $\theta_{t,6M} = \frac{2}{3}\theta_{t,3M} + \frac{1}{3}\theta_{t,1Y}$. Table A.1 summarises the start dates of the convenience yields in our study. The data runs through 2020:12.

Table A.1: Du, Im, and Schreger (2018a) Convenience Yield Data Start Dates

Country	6-month Start Date	10-year Start Date
Australia	1997:10	1997:03
Canada	2001:02	2000:02
Euro Area	1999:01	1999:01
Japan	1997:06	1997:06
Switzerland	1998:09	1998:09
U.K.	1997:01	1997:01

Notes: The 6-month start date is the max{3-month, 1-year } start date.

We use nominal zero-coupon government bond yields at 6-month and 10-year maturities for 7 industrialised countries: U.S., Australia, Canada, euro area, Japan, Switzerland and U.K. The end-date of our sample (2020:12) is restricted by the availability of these bond yields. Table A.2 summarises the sources of nominal zero-coupon government bond yields for the economies in our study.

Table A.2: Yield Curve Data Sources

Country	Sources
U.S.	Gürkaynak, Sack, and Wright (2007)
Australia	Reserve Bank of Australia
Canada	Bank of Canada
Euro Area	Bundesbank (German Yields)
Japan	Wright (2011) and Bank of England
Switzerland	Swiss National Bank
U.K.	Anderson and Sleath (2001)

Notes: Data ends December 2020.

Exchange rate data is from *Datastream*, reflecting end-of-month spot rates *vis-à-vis* the U.S. dollar. Finally, we obtain gross equity price indices of large and mid-cap sized firms for the U.S., Australia, Canada, Euro Area, Japan, Switzerland and the U.K. from *MSCI*. As with our other data, we use the end-of-month observations for these series.

B Inferring Convenience Yields from CIP Deviations

Jiang et al. (2021a) propose a method to infer the U.S. Treasury convenience yield from the U.S.'s CIP deviation (the Treasury basis), defined in (4), which we reproduce below. The main idea is that foreign investors derive a convenience yield not only from holding U.S. Treasuries, but also from holding foreign government bonds swapped into U.S. dollars using a forward contract (synthetic U.S. Treasuries). Since U.S. Treasuries are also a claim to dollars, Jiang et al. (2021a) posit that the convenience yield on the synthetic dollar position—the CIP deviation—is less the convenience yield on the U.S. Treasury θ by a factor β:

$$\theta_t^{(k)} = \frac{1}{1-\beta^{(k)}} CIP_t^{(k)} \tag{B.1}$$

A β equal to 1 would imply $\theta_t^{(k)} = CIP_t^{(k)}$, that is, that the convenience yield on U.S. Treasuries comes from them being a claim to U.S. dollars. Conversely, a β close to 0 would imply $\theta_t^{(k)} >> CIP_t^{(k)}$, that is, that the convenience of U.S. Treasuries arises from their liquidity and safety, rather than them being a claim to dollars. The coefficient β can be estimated from the data as follows

$$\beta = 1 - \frac{1}{1-\alpha_1^4} \frac{1}{\delta_1} \in \{0, 1\} \tag{B.2}$$

where α_1 is the persistence of an AR(1) process for the average U.S. CIP deviation across currencies and δ_1 is the marginal effect of innovations to CIP deviations on exchange rate movements. Both are discussed in detail below.

We implement the method on the 6-month and 10-year CIP deviation, those used in our paper, and the 1-year CIP deviation to match the maturity used by Jiang et al. (2021a). The coefficient α_1 is estimated from a quarterly AR(1) process for the average U.S. CIP deviation across the six remaining G.7 currencies $\overline{CIP}_t^{(k)}$, for a maturity k:

$$\overline{CIP}_{t+3}^{(k)} = \alpha_1 \overline{CIP}_t^{(k)} + \omega_t. \tag{B.3}$$

Table B.1 reports the results.

The estimation of δ_1 is in two steps. First, we construct quarterly innovations to the CIP deviation, $\Delta\widetilde{\overline{CIP}}_t^{(k)}$ as the residual from estimating:

$$\Delta\overline{CIP}_{t+3}^{(k)} = \gamma_0 + \gamma_1 \overline{CIP}_t^{(k)} + \gamma_2 (\overline{r_t^{*,(k)} - r_t^{(k)}}) + \omega_t \tag{B.4}$$

Table B.1: Autocorrelation in CIP Deviations

Vars	$\overline{CIP}_{t+3}^{(6M)}$	$\overline{CIP}_{t+3}^{(1Y)}$	$\overline{CIP}_{t+3}^{(10Y)}$
$\overline{CIP}_t^{(6M)}$	0.68***		
	(0.05)		
$\overline{CIP}_t^{(1Y)}$		0.80***	
		(0.04)	
$\overline{CIP}_t^{(10Y)}$			0.89***
			(0.03)
Observations	195	195	207
Within R^2	0.47	0.64	0.87

The results from this regression are reported in Table B.2.

Table B.2: Constructing CIP Innovations as Residuals to

Vars	$\Delta\overline{CIP}_{t+3}^{(6M)}$	$\Delta\overline{CIP}_{t+3}^{(1Y)}$	$\Delta\overline{CIP}_{t+3}^{(10Y)}$
$\overline{CIP}_t^{(6M)}$	-0.58***		
	(0.06)		
$\overline{r_t^{*,(6M)} - r_t^{(6M)}}$	154		
	(180)		
$\overline{CIP}_t^{(1Y)}$		-0.44***	
		(0.06)	
$\overline{r_t^{*,(1Y)} - r_t^{(1Y)}}$		104	
		(109)	
$\overline{CIP}_t^{(10Y)}$			-0.16***
			(0.04)
$\overline{r_t^{*,(10Y)} - r_t^{(10Y)}}$			-44
			(161)
Observations	198	198	210
R^2	0.29	0.23	0.09

In the second step, we estimate δ_1 by regressing these innovations, $\widetilde{\overline{CIP}}_t^{(k)} \equiv \omega_t$ where ω_t is the residual from regression (B.3), on quarterly exchange rate movements:

$$\Delta \bar{e}_{t+3} = \delta_1 \Delta \widetilde{\overline{CIP}}_t^{(k)} + \varepsilon_t \tag{B.5}$$

Table B.3 reports the results.

Using these estimates α_1 and δ_1, we find $\beta^{(1Y)} = 0.89$, which is similar to the value found by Jiang et al. (2021a) of $\beta^{(1Y)} = 0.9$. The values found for the 6-month maturity is $\beta^{(6M)} = 0.76$ and for the 10-year maturities is $\beta^{(10Y)} = 0.85$.

Table B.3: CIP Innovations and Exchange Rate Dynamics

Vars	$\Delta\overline{e}_{t+3}$	$\Delta\overline{e}_{t+3}$	$\Delta\overline{e}_{t+3}$
$\Delta\overline{\widetilde{CIP}}_t^{(6M)}$	-5.38***		
	(1.23)		
$\Delta\overline{\widetilde{CIP}}_t^{(1Y)}$		-14.7***	
		(1.97)	
$\Delta\overline{\widetilde{CIP}}_{t+3}^{(10Y)}$			-18.2***
			(2.88)
Observations	198	198	210
Within R^2	0.08	0.20	0.16

C Derivations

Proof of Proposition 1: Consider the exchange rate process:

$$\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} = \frac{M^*_{t+1}}{M_{t+1}} e^{\theta_{t,1}+\eta_{t+1}}$$

First, we verify that this satisfies Euler equations (11)-(14). Since $\theta^{H,H}_{t,1} = \theta^{F,F}_{t,1} = 0$, equations (11) and (12) are satisfied for any exchange rate process. However, equations (13) and (14) can only be satisfied by the process above if both:

$$\mathbb{E}_t\left[M_{t+1}\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}e^{\theta^{H,F}_{t,1}}\right] = \mathbb{E}_t\left[M^*_{t+1}\right] = \frac{1}{R^*_{t,1}},$$
$$\mathbb{E}_t\left[M^*_{t+1}\frac{\mathcal{E}_t}{\mathcal{E}_{t+1}}e^{\theta^{F,H}_{t,1}}\right] = \mathbb{E}_t\left[M_{t+1}\right] = \frac{1}{R_{t,1}}$$

which holds if $\theta_{t,1} \equiv \theta^{F,H}_{t,1} = -\theta^{H,F}_{t,1}$ and if:

$$\mathbb{E}_t\left[M^*_{t+1}e^{\eta_{t+1}}\right] = \mathbb{E}_t\left[M^*_{t+1}\right] = \frac{1}{R^*_{t,1}},$$
$$\mathbb{E}_t\left[M_{t+1}e^{-\eta_{t+1}}\right] = \mathbb{E}_t\left[M_{t+1}\right] = \frac{1}{R_{t,1}},$$

that is, since the SDFs and η_{t+1} are jointly log-normally distributed, if the following restrictions hold:

$$\mathbb{C}ov_t(m_{t+1}, \eta_{t,1}) = -\mathbb{E}_t[\eta_{t,1}] + \frac{1}{2}\mathbb{V}ar_t[\eta_{t,1}]$$
$$\mathbb{C}ov_t(m^*_{t+1}, \eta_{t,1}) = -\mathbb{E}_t[\eta_{t,1}] - \frac{1}{2}\mathbb{V}ar_t[\eta_{t,1}].$$

Taking log expansions of the exchange rate process, $\Delta e_{t+1} = m^*_{t+1} - m_{t+1} + \theta_{t,1} + \eta_{t+1}$, and the domestic Euler equations, $\mathbb{E}_t[m_{t+1}] + \frac{1}{2}\mathbb{V}ar_t[m_{t+1}] = -r_{t,1}$ and $\mathbb{E}_t[m^*_{t+1}] + \frac{1}{2}\mathbb{V}ar_t[m^*_{t+1}] = -r^*_{t,1}$, we can write:

$$r^*_{t,1} - r_{t,1} + \mathbb{E}_t[\Delta e_{t+1}] = \frac{1}{2}\left(\mathbb{V}ar_t[m_{t+1}] - \mathbb{V}ar_t[m^*_{t+1}]\right) + \theta_{t,1} + \mathbb{E}_t[\eta_{t+1}],$$
$$\mathbb{E}_t[rx^{FX}_{t+1}] = \frac{1}{2}\left(\mathbb{V}ar_t[m_{t+1}] - \mathbb{V}ar_t[m^*_{t+1}]\right) + \theta_{t,1} + \mathbb{E}_t[\eta_{t+1}].$$

□

Proof of Corollary 1: Analogous to the log-normal case above, the conjectured exchange rate process $\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} = \frac{M^*_{t+1}}{M_{t+1}} e^{\theta_{t,1}+\eta_{t+1}}$ satisfies the four Euler equations if $\theta_{t,1} \equiv \theta^{F,H}_{t,1} = -\theta^{H,F}_{t,1}$ and if the following restrictions on the joint dynamics of the SDFs and η_{t+1} are satisfied:

$$\mathcal{L}_t[M_{t+1}e^{-\eta_{t+1}}] = \mathbb{E}_t[\eta_{t+1}] + \mathcal{L}_t[M_{t+1}]$$
$$\mathcal{L}_t[M^*_{t+1}e^{\eta_{t+1}}] = -\mathbb{E}_t[\eta_{t+1}] + \mathcal{L}_t[M^*_{t+1}]$$

Then, combining the log expansions of the domestic Euler equations (11) and (12):

$$-r^*_{t,1} = \log \mathbb{E}_t[M^*_{t+1}] = \mathcal{L}_t[M^*_{t+1}] + \mathbb{E}_t[m^*_{t+1}]$$
$$-r_{t,1} = \log \mathbb{E}_t[M_{t+1}] = \mathcal{L}_t[M_{t+1}] + \mathbb{E}_t[m_{t+1}],$$

with the log-expansion of the exchange rate process: $\Delta e_{t+1} = m^*_{t+1} - m_{t+1} + \theta_{t,1} + \eta_{t+1}$, we solve for $\mathbb{E}_t[rx^{FX}_{t+1}] = r^*_{t,1} - r_{t,1} + \mathbb{E}_t[\Delta e_{t+1}]$ and arrive at our expression:

$$\mathbb{E}_t[rx^{FX}_{t+1}] = \mathcal{L}_t[M_{t+1}] - \mathcal{L}_t[M^*_{t+1}] + \theta_{t,1} + \mathbb{E}_t[\eta_{t+1}]$$

□

Proof of Proposition 2: We begin by proving the unconditional relationship in (21). Starting from (19) and taking unconditional expectations, we have:

$$\lim_{k\to\infty} \frac{1}{k} \{\mathrm{D}\mathcal{L}[M_{t+k}] - \mathrm{D}\mathcal{L}(\mathbb{E}_t[M_{t+k}])\} = \lim_{k\to\infty} \frac{1}{k}\mathbb{E}[rx^{FX}_{t+k}] - \lim_{k\to\infty} \frac{1}{k}\theta_k - \lim_{k\to\infty} \frac{1}{k}\mathbb{E}[\eta_{t+k}]$$

where we have used that $\mathbb{E}[\mathcal{L}_t(x_{t+k})] = \mathcal{L}[x_{t+k}] - \mathcal{L}[\mathbb{E}_t(x_{t+k})]$. Then: (i) since the SDFs are stationary, we have that $\lim_{k\to\infty} \frac{1}{k}\{\mathcal{L}(\mathbb{E}_t[M^{(*)}_{t+k}])\} = 0$; and (ii) by proposition (6) in Alvarez and Jermann (2005), we know that $\lim_{k\to\infty} \frac{1}{k}\{\mathcal{L}[M_{t+k}]\} = \mathcal{L}[M^{\mathbb{P}}_{t+1}]$. Together, this gives (21).

The conditional relationship in equation (22) follows directly from applying the Alvarez and Jermann (2005) decomposition (8), $\mathcal{L}_t\left(M_{t+1}\right) = \mathcal{L}_t\left(M^{\mathbb{P}}_{t+1}\right) + \mathbb{E}_t rx^{(\infty)}_{t+1}$, to equation (18) from Corollary 1. Using the definition of $rx^{(\infty),CT}_{t+1}$ from (3) and adding and subtracting the convenience yield on long-maturity bonds $\theta_{t,\infty}$ then gives (22), which highlights a conditional relationship between permanent SDF risk and the convenience yield on long-maturity Treasuries.

□

D Robustness and Additional Empirical Results

In this appendix, we provide additional empirical results and robustness that complement the empirical findings from the main text. Section D.1 provides some further summary statistics; section D.2 re-estimates the panel regressions and VAR used to investigate Corollary 1 by decomposing the U.S. total risk into its permanent and short-run components; section D.3 highlights that our permanent-risk results related to Proposition 2 are robust to including the convenience yield curve slope as a control in the panel regressions and as an endogenous variable in the VAR; and section D.4 showcases further impulse responses to monetary policy shocks.

D.1 Additional Summary Statistics

To complement the summary statistics from the main text, which focused on trends in overall and permanent U.S. risk along with the channels of adjustment to changes in permanent risk, in this section we document the evolution of relative short-run (residual) risk $\mathrm{D}\mathcal{L}_t(M_{t+1}^{SR})$, the exchange rate risk premium rx_{t+1}^{FX}, and the convenience yield on short-maturity U.S. Treasuries $\theta_{t,1}$. The results are displayed in Figure D.1 and highlight that, unlike for permanent risk and its long-run channels of adjustment, there is little trend movement in any of these quantities over the past two decades. These non-trending short-run variables motivate our investigation into long-run relationships in this paper.

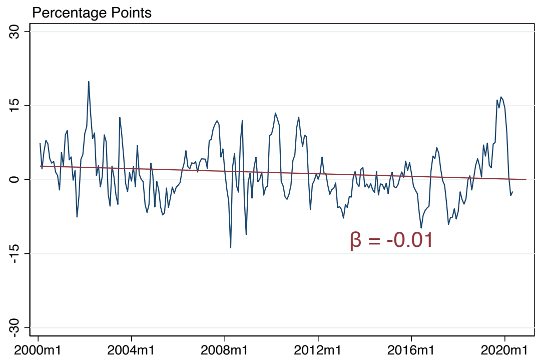
D.2 Decomposing U.S. Relative Risk Shocks into Permanent and Short-Run

In this section, we build on and re-interpret some of the results from the main text by documenting the distinct adjustments of short-maturity Treasury convenience yields and the exchange rate risk premium to permanent and short-run risk. We begin by re-estimating our overall-risk panel regressions from section 5.1, but with $\mathrm{D}\mathcal{L}_t(M_{t+1})$ replaced with its decomposition into relative permanent $\mathrm{D}\mathcal{L}_t(M_{t+1}^{\mathbb{P}})$ and short-run $\mathrm{D}\mathcal{L}_t(M_{t+1}^{SR})$ risk. The results are displayed in Table D.1 and highlight that, contemporaneously, the adjustment of short-maturity convenience yields is due primarily to changes in U.S. relative permanent risk while the exchange rate risk premium adjusts primarily to changes in U.S. relative short-run risk.

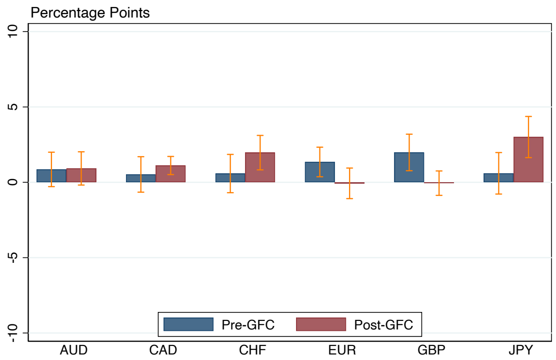
Next, we repeat this exercise in our VAR analysis of Corollary 1. We replace the U.S. relative overall risk variable ordered first the VAR with both two variables—U.S. permanent and short-run relative risk—and study the distinct impulse responses to their respective shocks.

Figure D.1: Short-Run U.S. Risk, Dollar Risk Premia and Short-Maturity Convenience

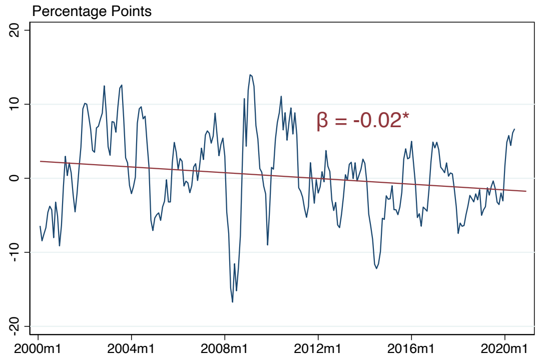
(a) U.S. Relative Short-Run SDF Risk



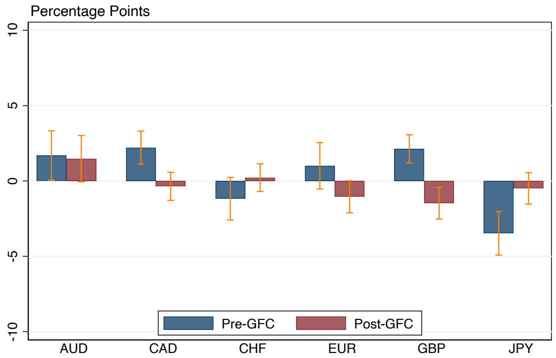
(b) U.S. Relative Short-Run SDF Risk Pre/Post GFC



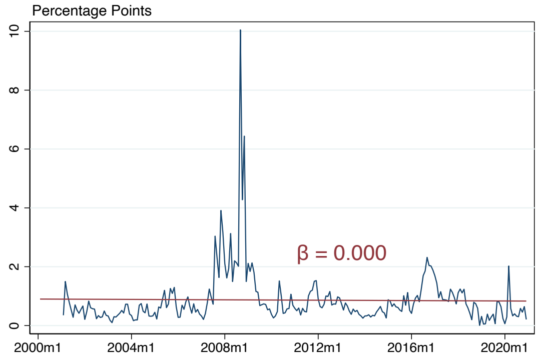
(c) U.S. Exchange-Rate Risk Premium



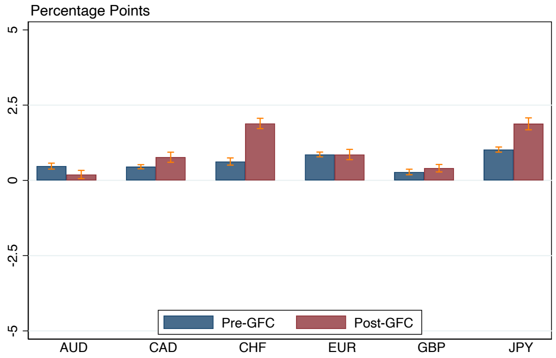
(d) U.S. FX Risk Premium Pre/Post GFC



(e) U.S. 6-Month Treasury Convenience Yield



(f) U.S. 6-Month Treasury CY Pre/Post GFC



Note. Panels D.1a, D.1c and D.1e display the time-series of U.S. short-run risk, the dollar exchange rate risk premium, and the short-maturity Treasury convenience yield relative to the corresponding unweighted average risk of G.7 currencies from 2000:M2 to 2020:M12. * signifies that the slopes (βs) of the best-fit lines are greater than zero at the 10% significance level based on Newey and West (1987) standard errors with 4 lags. The bars in Panels D.1b, D.1d, and D.1f reflect the level of average U.S. short-run risk, the dollar exchange rate risk premium, and the short-maturity Treasury convenience yield relative to a given G.7 currency either pre- or post-GFC. The pre-GFC period ends in 2006:M12; its start is currency-specific and is dictated by the availability of convenience yield data from Du et al. (2018a). The post-GFC period is from 2007:M1 to 2020:M12. Error bars are 68% confidence intervals constructed using Newey and West (1987) standard errors with 4 lags.

Table D.1: Channels of Adjustment to U.S. Relative Risk

(a) Short-Maturity Convenience Yield

Vars	(1) $\theta_{i,t,1}$	(2) $\theta_{i,t,1}$	(3) $\theta_{i,t,1}$	(4) $\theta_{i,t,1}$
$\mathrm{D}\mathcal{L}_t(M_{i,t+1})$	-.006	-.007*		
	(.004)	(.004)		
$\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1})$			-.006	-.007*
			(.004)	(.004)
$\mathrm{D}\mathcal{L}_t(M^{SR}_{i,t+1})$			-.001	-.004
			(.008)	(.009)
Controls	No	Yes	No	Yes
Observations	1551	1551	1551	1551
Within R^2	0.01	0.01	0.01	0.01

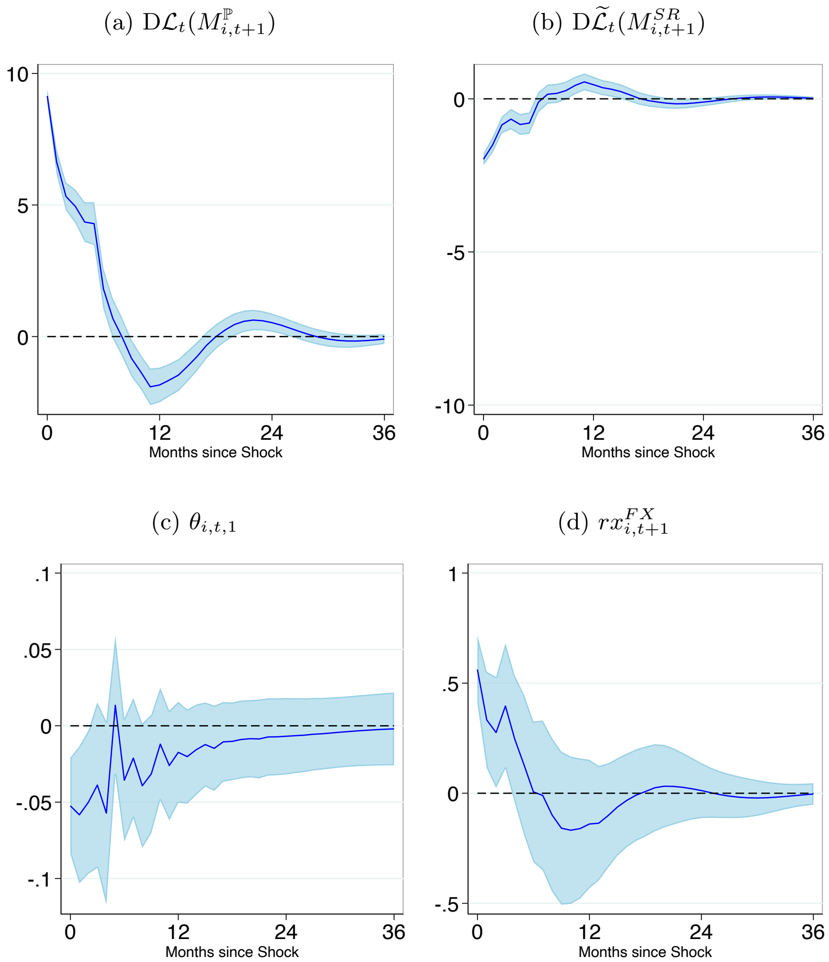
(b) Exchange Rate Risk Premium

Vars	(1) $rx^{FX}_{i,t+1}$	(2) $rx^{FX}_{i,t+1}$	(3) $rx^{FX}_{i,t+1}$	(4) $rx^{FX}_{i,t+1}$
$\mathrm{D}\mathcal{L}_t(M_{i,t+1})$	.139***	.141***		
	(.029)	(.029)		
$\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1})$			.122***	.123***
			(.029)	(.029)
$\mathrm{D}\mathcal{L}_t(M^{SR}_{i,t+1})$			.383***	.384***
			(.069)	(.069)
Controls	No	Yes	No	Yes
Observations	1551	1551	1551	1551
Within R^2	0.09	0.09	0.15	0.15

Note. Table D.1a presents the coefficient estimates from the Corollary 1 regression (23) using relative U.S. overall risk $\mathrm{D}\mathcal{L}_t(M_{t+1})$ as well as overall risk decomposed into permanent $\mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{t+1})$and short-run risk $\mathrm{D}\mathcal{L}_t(M^{SR}_{t+1})$. Table D.1b does the same for the exchange rate risk premium (regression D.1a). The panel regressions are estimated for six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD in an unbalanced sample from 1997:M1–2020:M12 with currency fixed effects. *, **, and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively, using Driscoll and Kraay (1998) standard errors (reported in parentheses).

Figure D.2 highlights that a rise in U.S. permanent risk leads to a significant reduction in the convenience yield on short-maturity U.S. Treasuries and a mild rise in the dollar risk premium. Conversely, as shown in Figure D.3 a rise in U.S. short-run risk leads to an *increase* in the short-maturity U.S. convenience yield and produces a relatively large and persistent increase in the dollar risk premium, as compared to the permanent risk shock. The opposing signs of the dynamic response of short-maturity convenience yields to permanent versus transitory shocks rationalizes the limited response of these non-pecuniary returns to total risk innovations. Further, it shows that convenience yields are "well-anchored" to relative-risk fundamentals—in the sense that higher risk reduces the safe-asset status of U.S. dollar bond—only in the case of permanent risk. Transitory, short-run, risk does not compromise the ability of the U.S. to earn *greater* seigniorage and benefit from its safe haven status.

Figure D.2: Shocks to U.S. Relative Risk on LR and SR Convenience Yields and Dollar Premia

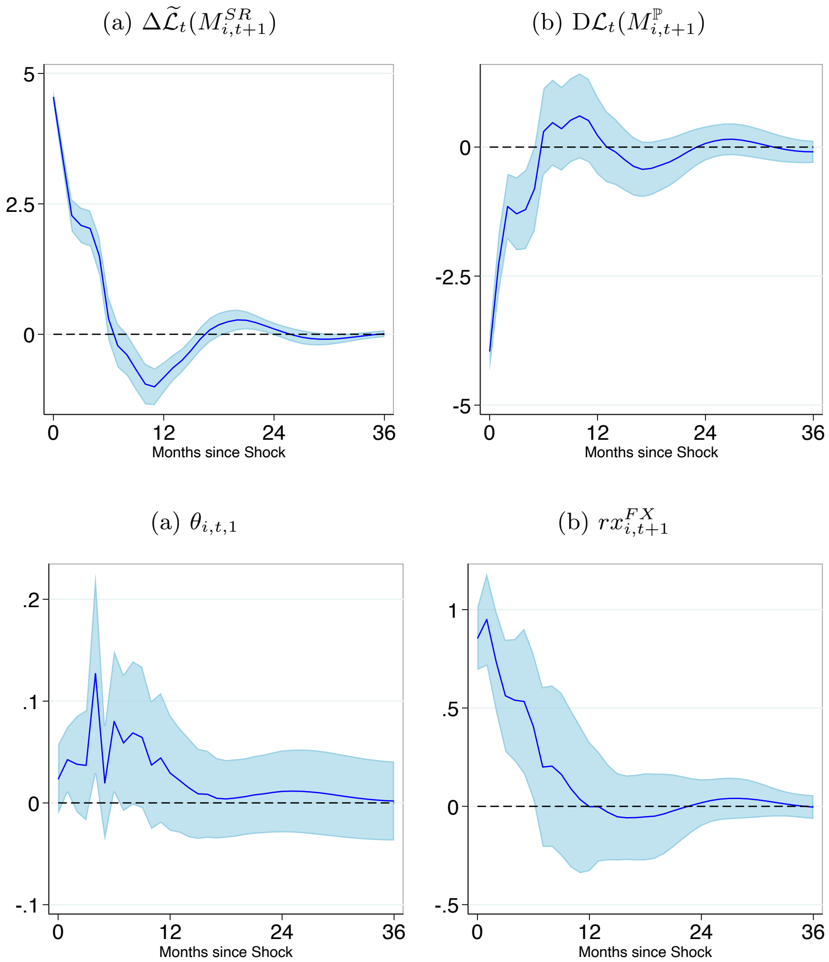


Note. Figure D.2 presents the impulse response functions to a 1/2 standard deviation shock to U.S. relative permanent risk $D\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1})$ (panel D.2a) for U.S. relative short-run risk (panel D.2b) short-maturity U.S. convenience yields (panel D.2c) and dollar risk premia (panel D.2d) from a panel VAR(6) containing six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points. The ordering is $[D\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1}), \mathcal{L}_t(M^{SR}_{i,t+1}), \theta_{i,t,1}, rx^{FX}_{i,t+1}]$.

D.3 The Convenience Yield Curve Slope as an Endogenous Variable

In the main text, motivated by our unconditional long-run equilibrium relation and to avoid colinearity between $\theta_{t,\infty}$ and θ_t^{slope}, we omitted the slope of the convenience yield curve when taking Proposition 2 to the data using contemporaneous panel regressions and treated it as an exogenous variable in our VARs. In this section, we show that our baseline results are robust to including the convenience yield slope in the panel regressions and as an endogenous variable in the VARs.

Figure D.3: Shocks to U.S. Relative Risk on LR and SR Convenience Yields and Dollar Premia



Note. Figure D.3 presents the impulse response functions to a 1/2 standard deviation shock to U.S. relative short-run risk $\mathrm{D}\mathcal{L}_t(M^{SR}_{i,t+1})$ (panel D.3a) for U.S. relative permanent risk (panel D.3b) short-maturity U.S. convenience yields (panel D.3a) and dollar risk premia (panel D.3b) from a panel VAR(6) containing six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points. The ordering is $[\mathcal{L}_t(M^{SR}_{i,t+1}), \mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1}), \theta_{i,t,1}, rx^{FX}_{i,t+1}]$.

While the first two columns of Table **??** are the same as in the main text, the next two differ in that they include the convenience yield curve slope as a control. The results highlight that a rise in U.S. permanent risk remains associated with a decline in the convenience of long-maturity Treasuries and a rise in dollar carry trade returns on long-term bonds, even when controlling for the slope. The final two columns study the contemporaneous association between U.S. relative permanent risk on the slope of the convenience yield curve. They highlight the mixed results. Without controls, greater U.S. risk increases the slope of the curve, reflecting the greater contemporaneous fall in long-maturity convenience yields compared to short-maturity ones. Conversely, when controlling for long-maturity convenience yields and long-run dollar

Table D.2: Channels of Adjustment to Relative Permanent Risk

Vars	(1) $\theta_{i,t,\infty}$	(2) $rx_{i,t+1}^{(\infty),CT}$	(3) $\theta_{i,t,\infty}$	(4) $rx_{i,t+1}^{(\infty),CT}$	(5) $\theta_{i,t}^{slope}$	(6) $\theta_{i,t}^{slope}$
$D\mathcal{L}_t(M_{i,t+1}^{\mathbb{P}})$	-.024***	.200***	-.015**	.232***	.021***	-.004
	(.006)	(.028)	(.006)	(.029)	(.007)	(.004)
Controls	No	No	Yes	Yes	No	Yes
Observations	1597	1597	1551	1551	1551	1551
Within R^2	0.05	0.15	0.71	0.19	0.03	0.70

Note. Table D.2 presents coefficient estimates from the Proposition 2 regressions (25) and (26) in Table 1b. The panel regressions are estimated for six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD in an unbalanced sample from 1997:M1–2020:M12 with currency fixed effects. *, **, and *** denote statistically significant point estimates at 10%, 5% and 1% significance levels, respectively, using Driscoll and Kraay (1998) standard errors (reported in parentheses).

carry trade returns, the point-estimate changes sign but is insignificant.

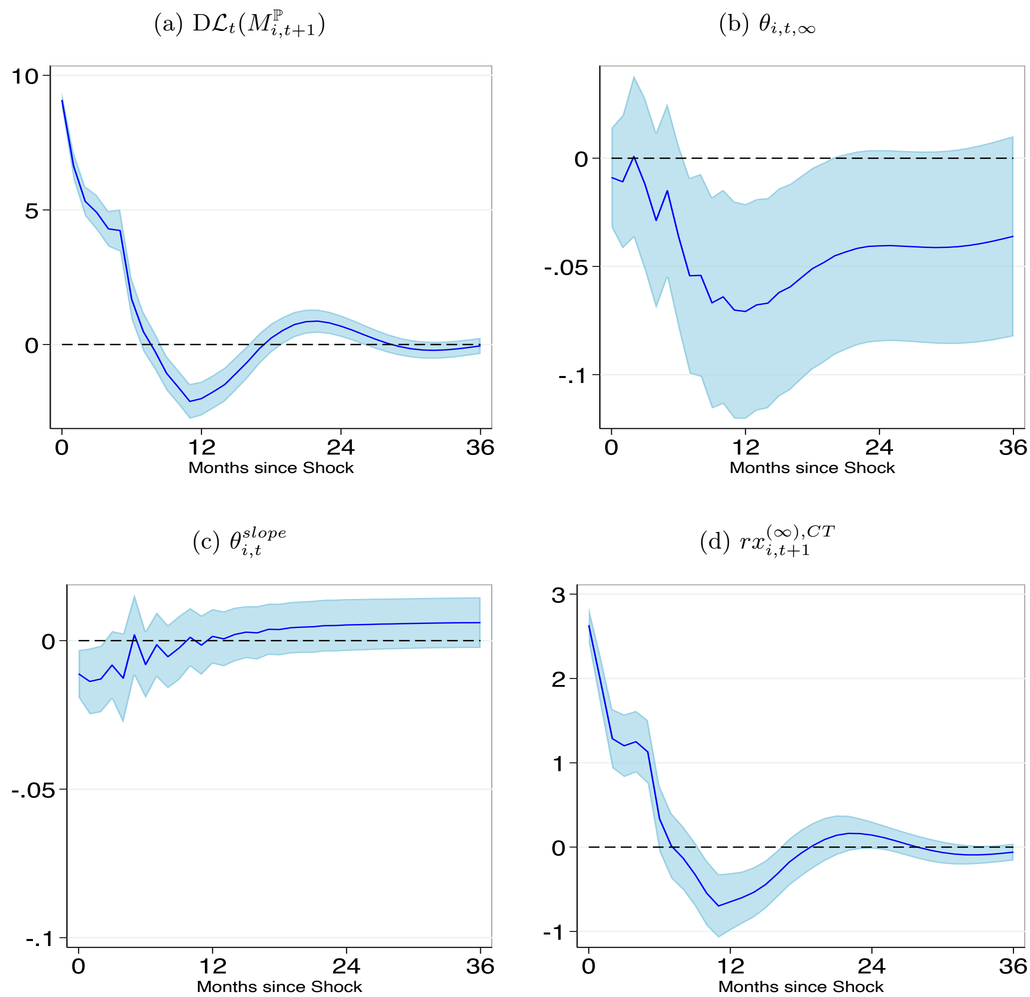
Next, we add the convenience yield curve slope as an endogenous variable to our VAR with permanent risk shocks. The results are displayed in Figure D.5 and highlight that a rise in U.S. permanent risk continues to induce a significant decline in the long-maturity Treasury convenience yield. The effect on the slope of the convenience yield curve is quite small. Although the slope falls at first, reflecting a larger on-impact reaction of the short-maturity convenience yield, eventually it reverses and becomes positive, although this is not statistically significant. Still, it suggests a tendency for a permanent flattening of the convenience yield curve slope in response to a rise in U.S. permanent risk.

Finally, we perform the same exercise with our permanent-risk VAR augmented with the monetary policy shock. The results are similar for the existing variables from the main text: an easing shock leads to a rise in U.S. permanent risk, a fall in long-maturity Treasury convenience and an on-impact increase of the dollar carry trade returns on long-maturity bonds, followed by an overshooting. The new variable, the convenience yield slope, behaves as in response to the permanent risk shock: it falls at first before eventually reverting and overshooting, although this overshoot is not statistically significant.

D.4 Additional Monetary Policy Results

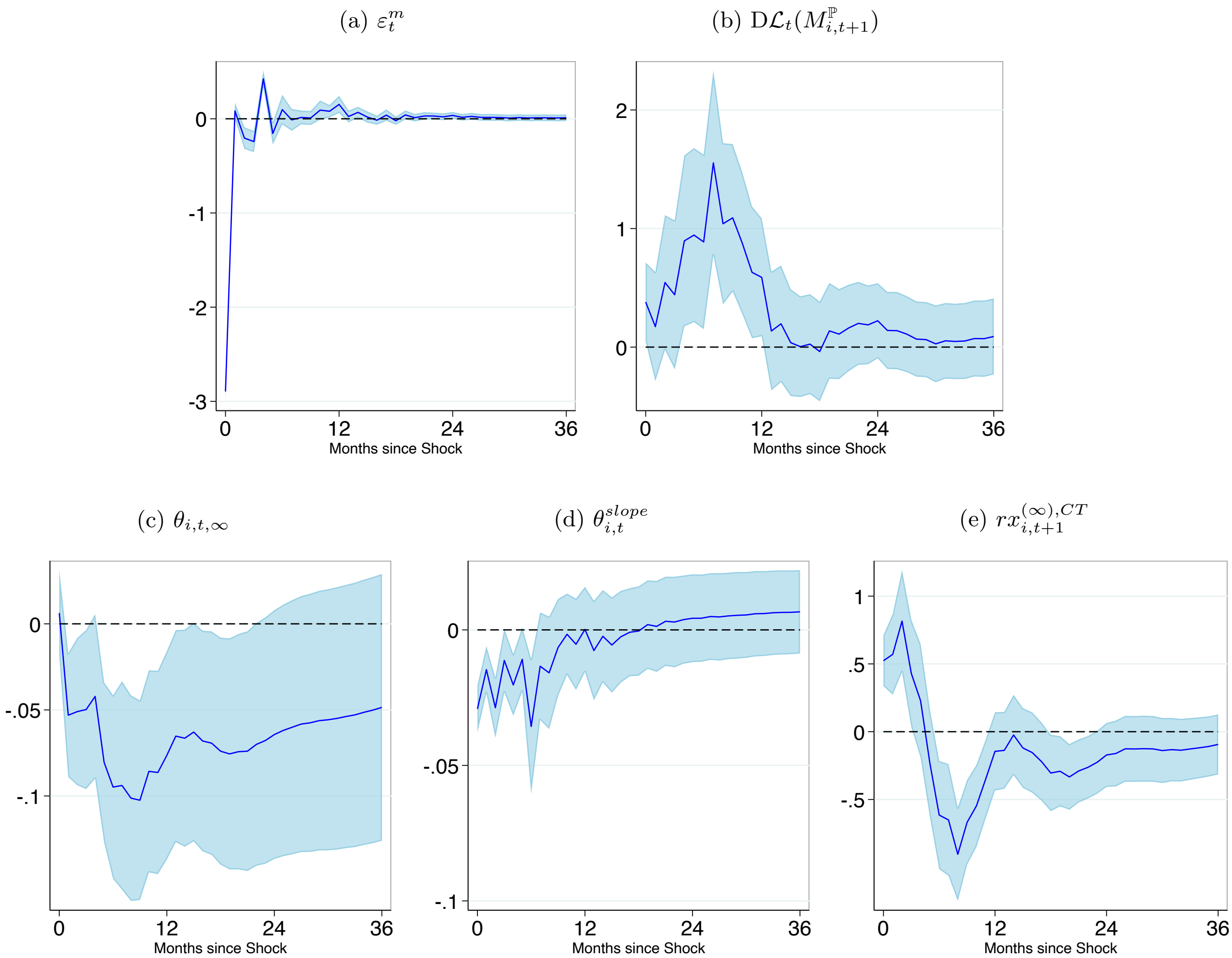
In this section, we report the complete set of impulse responses, including long-maturity dollar carry trade returns, for Figure 7 from the main text.

Figure D.4: U.S. Relative Permanent Risk Shocks on Long-Run and Slope of Convenience Yield and Dollar Premia



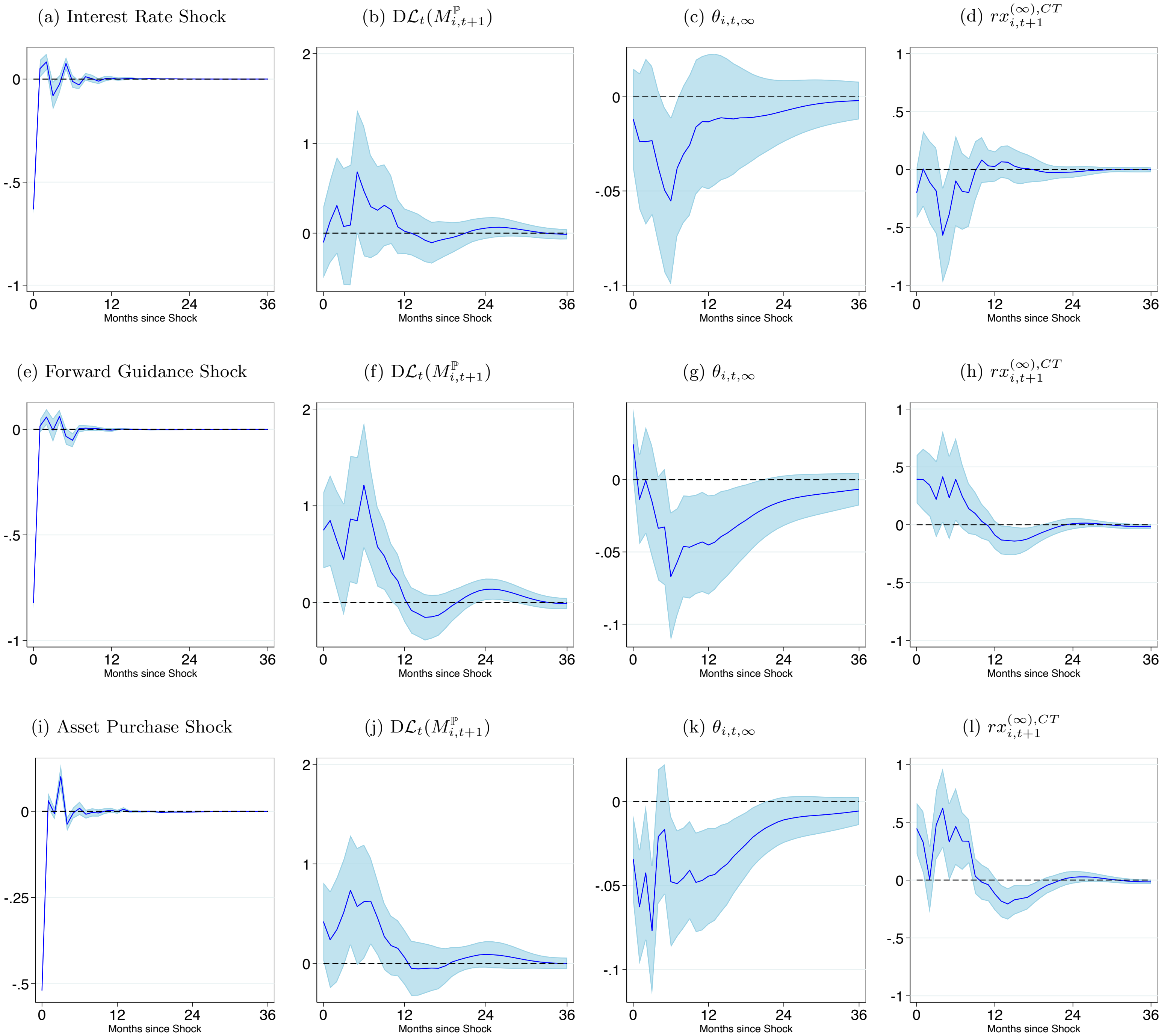
Note. Figure D.4 presents the impulse response functions to a 1/2 standard deviation shock to U.S. relative risk $D\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1})$ (panel D.4a) for long-maturity U.S. convenience yields (panel D.4b), the slope of the convenience yield curve (panel D.4c), and long-run dollar carry trade returns (panel D.4d) from a panel VAR(6) containing six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points. The ordering is $[D\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1}), \theta_{i,t,\infty}, \theta^{slope}_{i,t}, rx^{(\infty),CT}_{i,t+1}]$.

Figure D.5: Transmission of Monetary Policy Shocks to U.S. Relative Permanent Risk, Long-Run and Slope of Convenience Yields and Long-Run Dollar Premia



Note. Figure D.5 presents the impulse response functions to a 1/2 standard deviation monetary policy easing shock (panel D.5a) for U.S. relative permanent risk (panel D.5b), long-maturity U.S. convenience yields (panel D.5c), the slope of the convenience yield curve (panel D.5d), and long-run dollar carry trade returns (panel D.5e) from a panel VAR(7) with six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points. The ordering is $[\varepsilon_t^m, \mathrm{D}\mathcal{L}_t(M_{i,t+1}^{\mathbb{P}}), \theta_{i,t,\infty}, \theta_{i,t}^{slope}, rx_{i,t+1}^{(\infty),CT}]$.

Figure D.6: Transmission of U.S. Interest Rate, Forward Guidance and Asset Purchase Shocks



Note. Figure D.6 presents the impulse response functions, from separate VARs, to 1 standard deviation expansionary interest rate shocks (Panels D.6a, D.6b, D.6c, D.6d), forward guidance shocks (Panels D.6e, D.6f, D.6g, D.6h), and asset purchase shocks (Panels D.6i, D.6j, D.6k, D.6l), respectively, for U.S. relative permanent risk, long-maturity U.S. convenience yields and long-run dollar carry trade returns. The IRFs are from a panel VAR(6) with six currencies—AUD, CAD, CHF, EUR, GBP, JPY—relative to the USD. The sample runs from 1997:M1–2020:M12 and is unbalanced. Light blue shadings represent 90% confidence intervals constructed using robust standard errors generated from 200 Monte-Carlo Simulations. Y-axis is in percentage points, except for ε^m_t, which is in basis points. The ordering is $[\varepsilon^m_t, \mathrm{D}\mathcal{L}_t(M^{\mathbb{P}}_{i,t+1}), \theta_{i,t,\infty}, rx^{(\infty),CT}_{i,t+1}]$.