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Unconventional Monetary Policy Spillovers and the (In)convenience of Treasuries*

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ABSTRACT

Using high frequency data, we find that spillovers to the U.S. yield curve from the European Central Bank increased following the Global Financial Crisis, and strengthened when the U.S. normalized policy out of sync with other advanced economies. These spillovers were amplified by a contemporaneous waning in the ”convenience” of Treasuries. This provides evidence for a portfolio balance channel of transmission that is time-varying based on the non-pecuniary characteristics of Treasuries. We rationalize these facts using a two-country model of preferred habitat investors, where time-varying price-elasticity of demand for Treasuries gives rise to time-varying spillovers.

Keywords: Treasuries, convenience yield, monetary policy, international spillovers, quantitative easing, quantitative tightening, preferred habitat investors.

JEL Codes: E44, E52, F42, G12.

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1 Introduction

Since the end of the Second World War, U.S. Treasury securities have occupied a singular role in the international financial system as the world's unrivaled safe asset. Their privileged status derives not only from cash flows free of default risk, but also from their unmatched "convenience." Deep and liquid markets, broad regulatory compatibility, and the ability to serve as high-quality collateral for a diverse set of financial institutions combine with the U.S. dollar's reserve currency status to grease the wheels of the global financial system. As a consequence of the dollar's ubiquity in international trade and finance, safe dollar-based fixed income assets—Treasuries in particular—command a persistent premium in their pricing, reflecting structural demand from domestic and international investors. This premium, often termed the "convenience yield," captures the value that investors derive from the non-pecuniary benefits of holding Treasuries relative to other instruments with comparable credit risk.

Brunnermeier et al. (2024) evocatively liken Treasuries to a "good friend" — ever valuable and ever tradable, even in adverse conditions. Due to their non-remunerative properties, demand for Treasuries has come to be treated as relatively inelastic (Krishnamurthy and Vissing-Jorgensen (2012)). However, developments since the Global Financial Crisis (GFC) strongly suggest that these characteristics, and therefore the elasticity of Treasury demand, can vary with time. Seismic shifts in the market for Treasuries since the GFC have engendered explosive growth in the literature on the changing uniqueness or convenience thereof. Growing net supply of Treasuries (Greenwood et al. (2015); Krishnamurthy and Vissing-Jorgensen (2012); Nagel (2016)), falling intermediation capacity of dealer banks due to post-GFC regulatory reforms ((Du, Hébert, & Li, 2023), Du, Hébert, and Huber (2023), Duffie (2023); Klingler and Sundaresan (2023)), persistently under- and then over-target inflation (Campbell et al. (2017); Acharya and Laarits (2023)), and rising risk relative to other G7 economies (Corsetti et al. (2023)) have all seemingly contributed to a diminution in the convenience of Treasuries.

Against this backdrop, we provide new evidence that variation in the Treasury convenience yield is not merely an empirical artifact, but a powerful latent amplifier of international shock transmission to the U.S. Treasury market, and by extension to U.S. financial markets more broadly. In particular, we highlight how fluctuations in Treasury convenience influence both the magnitude and persistence of spillovers from unconventional monetary policy (UMP) in other advanced economies, with specific attention to post-GFC behavior of the U.S. term premia.[1] Prior to the GFC, spillovers from foreign central banks to the U.S. financial system were long thought to be limited, owing largely to the outsized role of the United States in global capital markets. Pre-GFC, the international transmission of conventional monetary policy, typically operating through short-rate adjustments affecting trade flows, exchange rate dynamics, and banking system balance sheets, was relatively muted compared to the dominant position of the United States in international finance (Ehrmann and Fratzscher (2005); Fratzscher et al. (2016); Brusa et al. (2020); Mueller et al. (2017); Rogers et al. (2014)).

The effective lower bound (ELB) on interest rates and the consequent expansion of unconventional monetary tools have profoundly altered this landscape. Although conventional (or short-rate-based) monetary policy spillovers remain modest, the global adoption of UMP has changed the picture substantially (Curcuru, Kamin, et al. (2018), Curcuru, De Pooter, and Eckerd (2018)). A growing body of work documents that unconventional monetary policy (UMP) in major advanced economies has substantial cross-border effects. For example, (Rogers, Scotti, & Wright, 2018), (Rogers et al., 2014), (Georgiadis & Gräb, 2016) show that ECB asset purchases lowered yields not only in the euro area but also in global bond markets, including the United States. (Miranda-Agrippino & Nenova, 2022) compare the spillovers from Fed and ECB actions, finding broadly similar patterns across the two central banks. However, while these studies establish that UMP spillovers to the U.S. exist, they do not explain why the magnitude of spillovers varies over time.

Theoretical and empirical studies suggest that the critical difference between conventional and unconventional policy lay in UMP's unique reliance on portfolio rebalancing to loosen domestic financial conditions, and that this same force intensifies international spillovers (Gourinchas et al. (in press), Kearns et al. (2023), (Bauer & Neely, 2014)). However, while the mechanisms and import of the portfolio rebalancing channel are well-appreciated theoretically, empirical estimates quantifying its import for the propagation of international shocks

[1] Throughout this paper, we use "spillovers" to refer specifically to the impact of monetary policy surprises by one central bank on the sovereign yield curve of another country.

remain scarce.

Our work fills these gaps by providing robust empirical evidence that portfolio rebalancing is the dominant channel for foreign spillovers to the U.S. Treasury market, and that the degree to which Treasuries are subject to portfolio rebalancing hinges on Treasuries' ”specialness”. When the convenience yield declines, Treasuries resemble other safe assets more closely, becoming subject to heightened rebalancing flows and increased U.S. vulnerability to external shocks.

In addition to this novel empirical contribution, our paper advances the convenience yield literature by moving beyond understanding the determinants and drivers of the convenience yield — a focus of much prior theoretical work (e.g., Hassan (2013), Gopinath et al. (2020), Mukhin (2022), Koijen and Yogo (2025)) — to studying the macroeconomic consequences of its time variation. While convenience yields have been modeled extensively (particularly for U.S. Treasuries), the implications of their variation for other macroeconomic aggregates and for the transmission of monetary policy are far less explored. We provide both theoretical reasoning and empirical validation that changes in convenience premia materially affect domestic financial market conditions and the effectiveness of monetary policy.

Along those lines our work most closely resembles Kekre and Lenel (2024). Although predominantly interested in the risk-bearing properties of international financial investors and the possibility of a safety trap, the authors are very clear in noting that ”all of the paper's insights only rely on time variation in the convenience yield”. Kekre and Lenel (2024) solve and calibrate a standard open economy New Keynesian model while adding heterogeneity of country-level risk bearing capacity and non-pecuniary utility derived from holding domestic bonds. Similar to money-in-the-utility function, the latter introduces a time-varying wedge in the Euler equations of the domestic investors which the authors label as the convenience yield. Shocks to this quantity are labeled ”safety shocks” and propagate throughout macroaggregates in a proportionate manner. Our approach to link the convenience yield to maturity-specific price elasticity of preferred habitat investors affords a more flexible way of modeling the portfolio balance channel of international monetary policy transmission. Rather than a global measure of convenience yield, we are able to address the impact of market-segmented changes in the non-pecuniary benefits of US Treasuries. This approach also cleanly addresses aspects of unconventional monetary policy which Kekre and Lenel (2024) cannot, most notably the differential impact of a time-varying convenience yield across the yield curve and on the efficacy of traditional monetary policy transmission channels.

Finally, we situate our contribution within the growing literature on ”exorbitant privilege” (Gourinchas and Rey (2007), Caballero et al. (2008), Chen et al. (2022)), a concept capturing the benefits accrued to the United States from the global dominance of its sovereign debt and currency. Theoretically, exorbitant privilege can be understood to insulate the U.S. economy from foreign monetary policy shocks by virtue of structural demand for Treasuries and their unique safe-asset status. However, our paper demonstrates that erosion of this privilege — closely associated with a declining convenience yield — substantially increases the susceptibility of U.S. Treasury yields to foreign monetary shocks and reduces the effectiveness of countervailing U.S. monetary policy. This erosion has broad implications for policymakers and financial market participants, calling into question longstanding assumptions regarding the resilience of U.S. financial markets in a changing global monetary environment.

Our approach is three-fold. First, we use high-frequency identification techniques to extract intradaily monetary policy surprises from European Central Bank (ECB) futures contracts and bond yields from Altavilla et al. (2019). While much of the existing spillover literature focuses on the Federal Reserve, we emphasize the ECB as a critical source of international monetary shocks, especially at the effective lower bound. Our analysis reveals that ECB-induced spillovers to the U.S. Treasury market have grown substantially over time, particularly affecting the long end of the yield curve through changes in the term premium, measured using the shadow rate term structure model (SRTSM) of Wu and Xia (2016). We find that the intensity and persistence of these spillovers are especially pronounced at intermediate and long maturities, where investor segmentation and duration risk exposure are strongest.

Second, we empirically link heightened spillovers directly to observable measures of Treasury specialness, starting with the maturity matched swap spread. Having established that spillovers rise when the convenience premium falls, we document that increases in net Treasury supply, rising costs of balance sheet intermediation (proxied by deviations from covered interest parity), and persistent deviations in inflation expectations all coincide with diminished convenience yields and stronger spillover effects from the ECB to U.S. Treasuries.

These findings suggest that the normalization of central bank balance sheets—particularly when other advanced economies continue large-scale asset purchases—can inadvertently exacerbate Treasury inconvenience and magnify cross-border spillovers.

Third, we extend the two-country preferred-habitat model of Gourinchas et al. (in press), in which segmented clienteles exhibit stable demand for bonds of particular maturities and currencies while global arbitrageurs reallocate under capital constraints. Our key innovation is to vary the slope of the demand curves for sovereign bonds by linking them to the observed convenience yield. Instead of assuming fixed elasticities, we treat variation in the convenience yield as a functional derivative of demand slope parameters. This approach captures how the marginal valuation of Treasuries and their substitutability vary over time, resulting in state-dependent spillover effects. This modeling innovation captures the empirical pattern that foreign asset purchases have more pronounced effects on U.S. yields during periods of waning Treasury convenience.

The model yields several testable implications that are consistent with our empirical findings. When Treasury convenience is high, demand curves are steep, limiting the responsiveness of U.S. term premia to foreign net bond supply shocks and providing insulation against spillovers. Conversely, low convenience flattens demand curves, increasing substitutability across sovereign bonds and intensifying co-movement in international long-term yields. Spillovers are most pronounced at maturities where duration exposure and investor segmentation are typically strongest, underscoring the nuanced link between market microstructure and cross-border transmission.

Taken together, these insights contribute to a more nuanced understanding of international monetary policy transmission in segmented global bond markets. Rather than treating U.S. financial insulation from foreign shocks as fixed or guaranteed by institutional prominence, our results reveal that such insulation is endogenous and state-dependent. Periods of rapid Treasury supply growth or diminished investor demand for safety flatten the demand curve and increase vulnerability to global shocks. This vulnerability reflects not only shifts in global risk sentiment or monetary policy scale, but rather fundamental structural features of sovereign bond demand.

Time-varying elasticity of demand for Treasuries has important implications for both fiscal and monetary policy. For instance, our results suggest that the persistently low long-term interest rates and yield curve inversions observed between the GFC and the Covid-19 pandemic were driven in part by international spillovers fueled by the combination of U.S. quantitative tightening and large-scale asset purchases by other advanced economies. By removing expectations for the Federal Reserve to absorb Treasury issuance, quantitative tightening increased net Treasury supply and reduced private demand. Simultaneously, the tightening of U.S. monetary policy dampened expected returns on long-term Treasuries. Dealers and leveraged investors, constrained by balance sheet costs, struggled to intermediate increased supply, resulting in diminished Treasury convenience. In this environment, ongoing large-scale asset purchases in the Euro Area further depressed long-term U.S. Treasury yields, while U.S. policy tightening raised short-term rates, reshaping the yield curve in a manner consistent with the predictions of our model. Our conclusions suggests that policy asynchronicity contribute to, and interact with, a declining convenience yield to hamper the effectiveness of U.S. conventional monetary policy in enacting its goals.

The remainder of the paper is organized as follows. Section 2 presents stylized facts on the relationship between channels of monetary policy spillovers at the ELB and the Treasury convenience yield. Section 3 lays out the mechanisms relating the elasticity of demand for Treasuries to the size of spillovers formally in a preferred habitat framework based on Gourinchas et al. (in press). Section 4 presents empirical evidence linking the growth of spillovers from the ECB to the (in)convenience of Treasuries. Section 5 explores (and largely rules out) additional potential channels of transmission, and Section 6 concludes.

2 Motivation and Background: Spillovers at the Effective Lower Bound

Over long stretches of history, central banks have largely conducted monetary policy by buying and selling short-term debt and, in most circumstances, target short-term interest rates. However, at the effective lower bound, the availability of cash as an asset prevents stimulus from decreasing the short-term policy rate indefinitely below zero. Beyond the effective lower bound of interest rates, central banks have enacted a suite of policies such as direct lending, liquidity provision to key credit markets, and large-scale asset purchases in pursuit of their mandates. While directed lending and liquidity provision featured prominently in the crisis phase of the last two recession, LSAPs became a key part of central banks' strategy to aid the recovery of aggregate demand. These large-scale asset purchases, coupled with forward guidance regarding the path of policy, aim specifically to lower long-term interest rates through heavier management of expectations and adjustments to term premia.[2]

To distinguish between conventional and unconventional monetary policy channels, it is convenient and common to consider the yield on an n-period risk-free bond as the average level of short-term interest rates over the maturity of the bond and a term premium:

$$Y_t^{(n)} = \mathbf{E}[\bar{Y}_{t,t+n}|I_t] + YTP_t^{(n)} \tag{1}$$

where $\mathbf{E}[\bar{Y}_{t,t+n}|I_t]$ is the average short-term rate expected to prevail over the period t to $t+n$ (that is, the component of the yield that would drive yield variation if the expectations hypothesis were to hold exactly), and $YTP_t^{(n)}$ is a maturity-specific term premium. The expected path of interest rates reflects beliefs about the likely path of short rate policy, which in turn is influenced by beliefs about the monetary policy rule, coupled with the likely path of growth and inflation. As the maturity of the bond lengthens, expectations about the path of interest rates gives way to risk, as individuals' perceptions of the path becomes less certain. The price and quantity of that risk is reflected in the term premium, which captures the additional required compensation for holding a long-term bond (duration risk).

Conventional monetary policy enacted through policy rates operates chiefly via the expected path of short-term interest rates, as both the policy decision and forward guidance alter agents' perceptions of future interest rates (Hamilton (2009)). The spillover effects from changes in the expected path of interest rates abroad primarily transmit through foreign growth rates, exchange rate adjustments, and risk taking by financial intermediaries.[3] Due to its size and centrality, the United States is comparatively insulated (although not immune) from these types of spillovers. Although conventional monetary policy can also move the domestic term

[2]Bernanke, Ben S. (19 November 2013) *Communication and Monetary Policy*. Retrieved from https://www.federalreserve.gov/newsevents/speech/bernanke20131119a.htm

[3]In small open economies, spillovers also emanate from changes in the world interest rate, depending on financial integration with the rest of the world.

premium by altering interest rate risk, there is little theoretical or empirical evidence to suggest that these changes generate international spillovers to the U.S.

Unconventional monetary policy also influences both terms of equation (1), either by signaling the central bank's intention to keep interest rates low over longer horizons, thereby reducing $\mathbf{E}[\bar{Y}_{t,t+n}|I_t]$, or by removing duration risk from the market (decreasing $YTP_t^{(n)}$). Regarding the first term of (1), expansionary forward guidance lowers the expected path of interest rates by communicating the central bank's intention to keep interest rates low (or to pursue ongoing asset purchases), committing often to a specific time horizon or state of fundamentals. This signaling channel of unconventional monetary policy carries the same potential to generate international spillovers as conventional means—international bank balance sheets, exchange rates, the current account.

However, as the maturity of an asset increases, the expected path of short interest rates explains less of the yield, in part because uncertainty increases with the time horizon. Thus, monetary policy at the effective lower bound also aims explicitly at decreasing longer term rates by decreasing term premia. While expansionary forward guidance can support the reduction of term premia by reducing interest rate risk, central banks can also directly target longer term interest rates by purchasing long duration assets, thereby reducing the effective supply of such assets and in turn raising their prices, lowering their yields, and decreasing the duration risk associated with holding them. As investors rebalance their portfolios in response to large scale asset purchases, the prices of the assets they acquire rise as well, decreasing their respective yields through the term premium and potentially prompting further rebalancing. "Restricted" or preferred habitat investors at home and abroad can amplify this portfolio balancing channel by purchasing additional long-dated assets, even as their prices rise in order to balance long-dated obligations on their balance sheets or to search for yield.[4]

From the central bank's perspective, the ideal investor reaction to LSAPs entails substituting the purchased asset with another domestic asset, like a safe corporate bond. However, in some circumstances and for some investors, foreign sovereign bonds are among the best substitutes. Thus, investors displaced from their target allocation by home LSAPs may re-

[4]Shin (2017) provides an illuminating example of long-term bond yield amplification through the duration balancing activities of German insurance firms.

store their balance sheet by purchasing safe, long duration sovereign bonds elsewhere, raising their price and lowering their yield. In this way, unconventional monetary policy uniquely potentiates spillovers because expansionary policy with strong portfolio balance effects has the potential to decrease *international* term premia at the long end of the yield curve.

2.1 Time varying spillovers

Altogether we should expect, and previous research has shown, that spillovers rise with the global adoption of unconventional monetary policy due to its unique reliance on long-duration assets (portfolio rebalancing). However, the literature on unconventional monetary policy transmission suggests that the strength of the portfolio balance channel can vary over time. For example, Droste et al. (2023) show that local supply effects of Treasury demand shocks are most obvious during periods of elevated risk. That is, LSAPs are less likely to be "spot" effective when the risk bearing capacity of arbitrageurs is high. Given that preferred habitat investors become less willing to substitute to other maturities of the same broad asset when risk bearing capacity is low, we might surmise that willingness to substitute between international markets could be suppressed under these conditions. Alternatively, investors may require a deeper discount to substitute their holdings, amplifying the change in price. Similarly, the strength of signaling and confidence channels may vary over time. For example, signals from other central banks leading up to an FOMC decision may become more influential with respect to the expected path of U.S. interest rates in an environment marked by elevated policy uncertainty.

To shed light on time variation in monetary policy spillovers, we being our analysis with a series of rolling regressions using zero coupon bond yields from Gürkaynak et al. (2007).[5] From March 2001, to December 2023, we regress n-year Treasury yields on ECB monetary policy surprises over windows covering 24 - 25 ECB announcement dates:

$$\Delta Y_t^{(n)} = \alpha + \beta MP_t^{eu} + \epsilon_t$$

Throughout our paper, monetary policy surprises (MP_t^{eu}) comprise the first principal

[5] https://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html

Figure 1: Monetary Policy Surprises

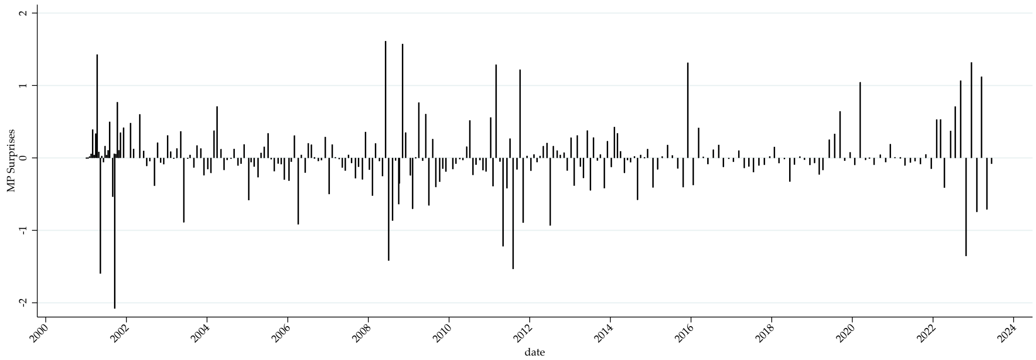


Figure 1 depicts ECB monetary policy surprises, which comprise the first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, 5-, 10-year German and French bond yields from Altavilla et al. (2019). The first principal component is normalized to raise the 24 month OIS by 10 basis points.

component of intraday changes in the yields on a number of assets, measured from 10-20 minutes pre-decision release to 10 - 20 minutes post-press conference, from Altavilla et al. (2019). These include 1-, 3-, 6-, 12-, and 24-month OIS rates, along with 5- and 10-year German and French bond yields. We favor this configuration of assets because monetary policy surprises derived from the cross-section of yields have the advantage of subsuming policies aimed at different maturities in the yield curve. Such compound measures summarize shocks to the overall stance of monetary policy both at and away from the effective lower bound. For ease of interpretation, we normalize monetary policy surprises such that a one unit tightening raises two year Euro OIS by 10 basis points. Figure 1 displays the time series of monetary policy surprises.

Figure 2a depicts rolling estimates of ECB spillovers to 1-, 5-, and 10-year U.S. zero coupon bond yields. Several patterns stand out. First, as previous work has shown, spillovers within the period of conventional monetary policy are not statistically different from zero, while the period of unconventional monetary policy is marked by growing spillovers at the longer end of the yield curve. Second, the time period in which spillovers become significant (i.e., when the rolling regressions integrate observations that pull the window's estimate away from zero) varies substantially from the time when the ECB began to engage in LSAPs.[6] In partic-

[6]Throughout this paper, we follow Bernanke (2009) and others and define quantitative easing as a central bank balance sheet expansion focused on the mix of loans and securities that the central bank holds, with explicit

ular, spillovers from the ECB become statistically significant when rolling regressions integrate observations starting in 2010, well before the start of the Expanded Asset Purchase Program (EAPP) in 2015 (and even before the "whatever it takes" speech in the summer of 2012). Moreover, while spillovers from the ECB last through most of the policy response to Covid, they began to dissipate not when the Pandemic Emergency Purchase Program (PEPP) ended in March of 2022, but when the Fed announced a start to LSAP tapering in November 2021. It seems, therefore, that the prevalence of spillovers to the U.S. emanates from more than the mere fact of ECB LSAPs.

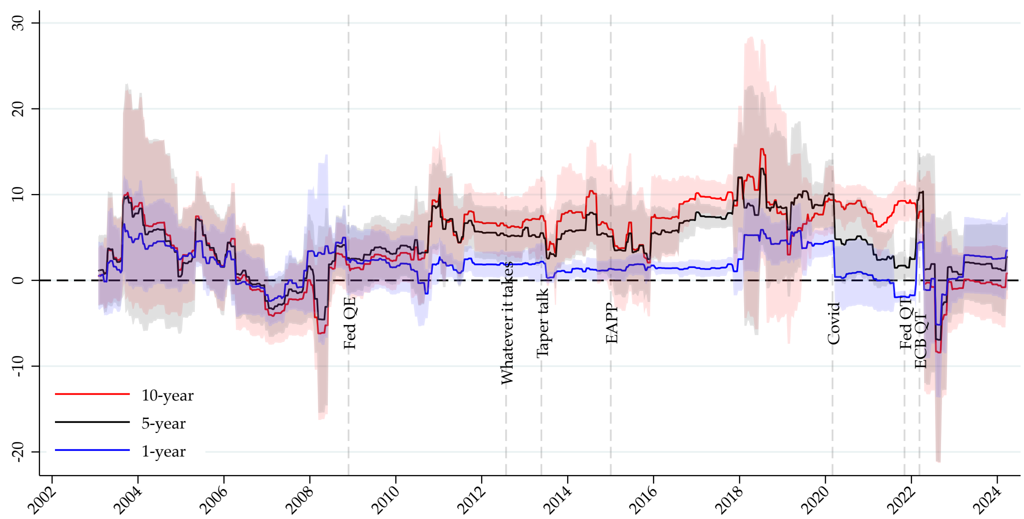
To begin to see why, we return to the decomposition from Equation 1 and repeat rolling regressions with elements of the 10-year yield decomposition as the dependent variable. Figure 2b plots the estimated impact of ECB monetary policy shocks on the 10-year term premium and expected path of short rates. Two features emerge that both validate the importance of the portfolio balance channel and suggest its explanatory power varies. First, during intervals marked by the largest spillovers, term premium effects surpass the expected path of short rates. Second, however, spillovers to the expected path of short rates also increase at various points. In particular, early spillovers from unconventional monetary policy comprise a more even mix of expected path and term premium spillovers, while later spillovers (roughly post-2014) feature larger term premium spillovers. This latter result stands out because the timing overlaps with the announced cessation of U.S. LSAPs; that is, term premium spillovers to the United States feature most prominently when the Federal Reserve is out of sync with other advanced economy central banks, working to withdraw stimulus while other central banks were stepping on the gas.

Taken together, these results suggest that international spillovers evolve not only between conventional and unconventional monetary policy regimes, but also within periods of UMP. While spillovers increase during periods of heavy multilateral large scale asset pur-

consideration on the effect this composition of assets affects credit conditions. This definition distinguishes the experience of the ECB from the Fed, the Bank of England, and the Bank of Japan. In contrast to these other central banks, the ECB's balance sheet expansion during its early crisis response mainly reflects its increased intermediation role and the growth of its lending to banks, which play a crucial part in financing the Euro area's private sector. While the other central banks orchestrated the growth of their balance sheets as part of their policies of quantitative easing, in the case of the ECB, the discretion of commercial banks and their need for refinancing drove balance sheet expansion. The contraction of the ECB's balance sheet that began in 2012 reflected the banks' declining need for liquidity following the reduction in financial fragmentation in the Euro area (de Sola Perea and Van Nieuwenhuyze (2014)).

Figure 2: Time-varying ECB spillovers to the U.S. yield curve

(a) 1, 5, 10-year Treasury yields



(b) 10-year yield decomposition

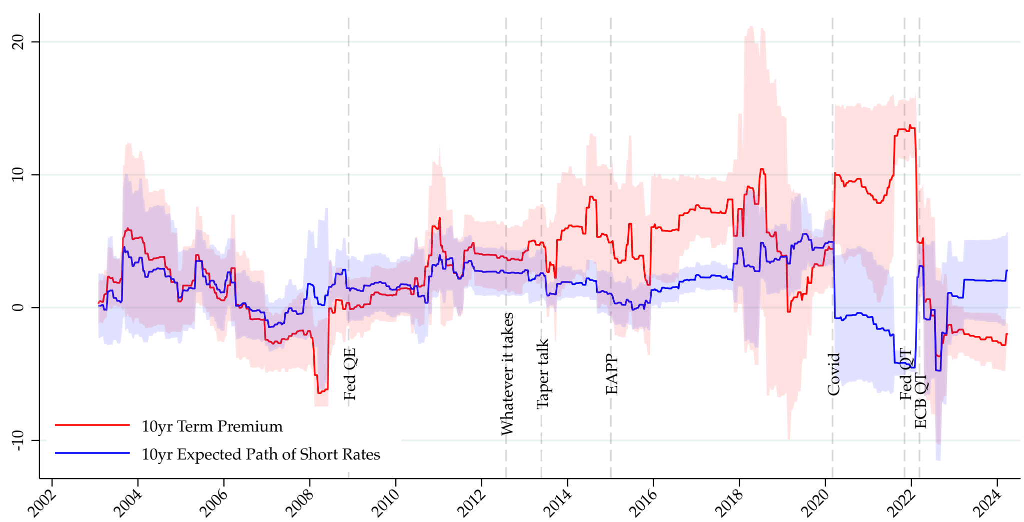


Figure 2 depicts estimates from a 700 business day (24 - 25 announcement) rolling regression of changes Treasury yields and its decomposition on ECB monetary policy shocks. Figure 2a shows the spillover coefficients to 1-, 5-, and 10-year zero coupon bond yields, while Figure 2b shows spillovers to the 10-year U.S. term premium and expected path of short rates. ECB surprises comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, plus 5-, 10-year German and French bond yields. Surprises are normalized to raise two year OIS by 10BP. Shaded areas denote 90% robust confidence intervals.

chases, the size of spillovers is clearly changing over time. Importantly, if we ignored the time varying nature of spillovers, we might conclude there are no spillovers to be found.[7]

2.2 The changing convenience of Treasuries

The natural question arising from this collection of estimates is: why? The U.S. Treasury market is the world's deepest, most liquid asset market, standing at the center of the U.S. and global financial systems. As a consequence of the dollar's ubiquity in trade and finance, safe dollar-based fixed income assets (and Treasuries in particular) command a premium in their pricing due to structural demand from both domestic and international actors. This premium is reflected in the spread between sovereign bond yields and other risk-free assets of the same maturity and domicile. While the convenience yield has many representations, convenience is ultimately in the eye of the beholder. Throughout this paper, we use the spread between sovereign bond yields and maturity matched overnight index swaps (the swap spread) because the relative convenience it prices matches the incentives of the types of investors we expect to generate spillovers in our model (i.e., those with a preference for sovereign-level credit quality and arbitrageurs).

Prior to the Global Financial Crisis, yields on Treasuries ran below the fixed interest rates on swaps of the same maturity. However, the years following the GFC brought about seismic shifts in the global financial and regulatory landscape, and contemporaneous to those changes emerged a diminution and even reversal of this relationship, shown in Figure 3. This attenuation in the convenience yield on Treasuries reflects a degradation in their special status. In the context of international portfolio rebalancing, the less special are long term Treasuries, the more directly substitutable they are for other risk-free long-duration assets, including other safe sovereign bonds.

As a first step to explore the relationship between spillovers to the U.S. term structure and the (in)convenience of Treasuries, we condition the response of Treasury yields to ECB spillovers on the estimated breakpoints in the ten year swap spread in Table 1 . Columns 1 and 2 use the break dates suggested by the Bai Perron test without additional processing. We

[7] In fact, a Bai Perron unknown break point test suggests *five* structural breaks in the relationship between ECB monetary policy shocks and 10-year Treasury yields.

Figure 3: Convenience Yields

(a) US swap spreads

(b) Breakpoints in the convenience yield

Breaks	Mean	Chg. from previous period	LL	UL
Oct 30, 2002	0.50	-0.35	Oct 19, 2002	Nov 10, 2002
Oct 8, 2008	0.12	-0.38	Sep 30, 2008	Oct 16, 2008
Apr 18, 2012	0.09	-0.03	Feb 12, 1294	Jun 23, 2730
Nov 18, 2015	-0.05	-0.14	Oct 2, 2014	Jan 3, 2017
Jun 5, 2019	0.00	0.05	Nov 23, 1936	Dec 16, 2101

Figure 3a shows the yield on the 10-year overnight index swap less that of 10-year Treasuries to represent the convenience yield. Table 3b displays estimated break points from a Bai Perron unknown break point test, the mean of the ten year swap spread between break dates, the change in mean relative to the previous period, and 95% confidence intervals.

see that, among break points after the onset of the ELB, the intervals book-ended by October 2008 - April 2012 and by November 2015 - June 2019 (rows 3 and 5) are associated with larger yield and term premium spillovers. In contrast, those starting with April 2012 and June 2019 (rows 2 and 6) are not. Two noteworthy observations emerge with respect to these apparent changes in the magnitude of spillovers. First, from April 2012 to November 2015 (row 4), the parameter values are stable compared to the time interval preceding, October 2008 - April 2012 (row 3). In fact, a Wald test for equality of coefficients does not reject the null hypothesis that the interaction terms are equal. During the interval from June 2019 to the end of the sample, the ECB ended its large scale asset purchase program and lifted off from the ELB. In fact, if we restricted the sample to end when the ECB raised interest rates July of 2022, the parameter values would be significant. This is a feature, rather than a bug insofar as it aligns with the notion that portfolio balance effects are unique to unconventional monetary policy, and in that way unconventional monetary policy potentiates international financial spillovers to the

U.S. Treasury market.

Table 1: Spillovers to the 10 year Treasury conditional on regimes of the convenience yield

	Baseline breakdates		**Alternative breakdates**	
	Y_{10}	TP_{10}	Y_{10}	TP_{10}
FFR_{t-1}	-0.10	-0.21	-0.15	-0.25
	(0.33)	(0.22)	(0.33)	(0.22)
Base effect	-0.40	-0.19	-0.39	-0.20
	(1.74)	(1.15)	(1.74)	(1.15)
2.) Oct. 2002 - Oct. 2008=1 × ECB	2.87	0.45	2.85	0.45
	(2.51)	(1.65)	(2.51)	(1.66)
3.) Oct. 2008 - Apr. 2012=1 × ECB	5.34^{**}	3.38^{**}		
	(2.34)	(1.54)		
4.) Apr. 2012 - Nov. 2015=1 × ECB	5.71	3.64		
	(3.81)	(2.51)		
5.) Nov. 2015 - Jun. 2019=1 × ECB	11.22^{***}	8.82^{***}		
	(4.14)	(2.73)		
6.) Post - Jun. 2019=1 × ECB	3.04	-1.67		
	(2.63)	(1.74)		
Oct. 2008 - Nov. 2015=1 × ECB			5.46^{**}	3.48^{**}
			(2.24)	(1.49)
Post - Nov. 2015=1 × ECB			4.95^{**}	-0.89
			(2.44)	(1.62)
Constant	1.95	2.52^{**}	2.14	2.64^{**}
	(1.56)	(1.03)	(1.55)	(1.03)
Observations	238	238	238	238

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1 displays estimates regressing changes in 10-year U.S. zero coupon bond yields and term premiaon the z-scores of ECB monetary policy shocks, conditional on a series of date indicators bookended by estimated breakpoints in the convenience yield (see Figure 3b). Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, along with 5-, 10-year German and French bond yields. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

Note, in addition, that the confidence bounds corresponding to these particular dates in Table 3b are remarkably wide, suggesting that the associated break is small, which visual inspection of Figure 3a corroborates. Therefore, columns 3 - 4 repeat the exercise with three break points. This exercise offers preliminary evidence that changes in the convenience of Treasuries shifted contemporaneously with the size of spillovers, particularly after momentous changes.

We postulate that time variation in the sensitivity of the U.S. yield curve to unconventional monetary policy spillovers emanates from the increased substitutability associated with diminishing non-pecuniary benefits. We suggest that when Treasuries command a large premium in their price, price-sensitive individuals nudged away from their pre-announcement allocation by the yield compression wrought by LSAPs (or the expectation of LSAPs) are unwilling to pay the premium because it prices characteristics not shared by the assets they seek to replace. The more price-sensitive the marginal investor, the lower would be their willingness accept the premium associated with the nonpecuniary benefits of Treasuries, and therefore the lower would be spillovers from foreign monetary policy.

3 A Model of Time Varying Portfolio Rebalancing

We explore the "specialness" of Treasuries as a key buffer of international spillovers to the United States through the lens of the portfolio rebalancing channel. Pointedly, when the ECB announced the public sector purchase program (PSPP) in March of 2015, policy makers explicitly referenced the accompanying fall in yields in terms not only of a reduction of duration risk, but also the "creation of scarcity" (Cœuré (2015)). In the face of increased scarcity, the preferences of habitat investors for the relative safety and liquidity of advanced economy sovereign bonds causes these assets' prices (and those of their closest substitutes) to rise because they cannot easily be replaced (Vayanos and Vila (2021a)). Empirical evidence on this front shows that net supply of debt can indeed explain domestic yields (e.g., Krishnamurthy and Vissing-Jorgensen (2011); Hamilton and Wu (2012); Greenwood and Vayanos (2014); Wolcott (2020); Blattner and Joyce (2020)).

The existence of a portfolio balance channel relies on the notion of partially segmented asset markets. If investors care only about risk-adjusted returns and view assets as otherwise perfect substitutes, then LSAPs would not affect yields at all, including those of domestic sovereign bonds (Curdia and Woodford (2011). On the other extreme, if markets are completely segmented, then LSAPs might pass through to other domestic assets, but would not generate international spillovers. In practice, investors likely fall between these two extremes. In partially segmented markets, investors view assets in different markets as imperfect substitutes, in which case asset purchases affect yields in both the domestic sovereign bond market and other markets (home and foreign).

Assuming markets are partially segmented, we should expect spillovers among safe sovereign bonds with similar maturities. In such an environment, portfolio rebalancing tends to direct funds toward the closest substitutes. The greater the dissimilarity between the substitute and the original asset, the larger the discount buyers require to hold the substitute; consequently, its price increases less and its yield declines less. The degree of substitutability among assets depends both on the extent to which they offer comparable benefits and on the price sensitivity of investors who do not value the differing attributes.

To analyze the mechanisms driving international spillovers of unconventional monetary policy to the U.S. Treasury market, we build on the preferred-habitat model developed by Gourinchas et al. (in press) (hereafter GRV). GRV's framework captures key features of global fixed income markets, including investor segmentation by bond maturity and issuer, as well as heterogeneous preferences that generate partially segmented asset markets. These segmentation patterns arise naturally due to institutional mandates, regulatory constraints, and risk management practices.

The GRV model formalizes demand and supply for sovereign bonds in a two-country setting with segmented markets and constrained global arbitrageurs. These arbitrageurs—limited in their risk-bearing by capital and balance sheet capacity—reallocate portfolios across maturities and countries to exploit relative value opportunities, partially bridging segmentation but never eliminating it. This framework captures how the interaction between preferred-habitat investors and constrained arbitrageurs shapes equilibrium yields, allowing investor preferences and market segmentation to influence bond pricing and the international transmission of monetary policy shocks through the portfolio balance channel.

However, GRV treat investor demand elasticities as fixed parameters, implicitly assuming constant substitutability and convenience characteristics of sovereign bonds over time.

This assumption limits the model's ability to explain observed time variation in the magnitude and persistence of international spillovers, especially in response to evolving market conditions and structural changes in the Treasury market.

Our contribution is to extend the GRV framework by allowing time variation in demand elasticities, linking them directly to the observed patterns in the convenience yield of U.S. Treasuries. We introduce a novel modeling approach that treats the convenience yield as a functional derivative of demand slope parameters, capturing how the "specialness" of Treasuries varies, whether due to factors such as net issuance, dealer balance sheet constraints, or inflation risk. This extension enables us to analyze how changes in Treasury convenience affect investor substitutability, thereby modulating the strength, persistence, and maturity structure of spillovers from foreign unconventional monetary policy.

To rigorously capture the dynamic impact of these elasticity shifts on yield sensitivities, we leverage tools—including functional derivatives and Malliavin calculus—which allow us to trace the time path of impulse responses in a continuous time dynamic stochastic general equilibrium setting. This provides a tractable and flexible framework to quantify how a decline in Treasury convenience amplifies cross-border transmission and reduces the effectiveness of conventional domestic monetary policy during periods of policy asynchronicity. Furthermore, endogenizing these elasticity shifts can be readily accomplished with the functional chain rule.

3.1 Comparative Statics in General Equilibrium

We take GRV as our starting point, in which investors exhibit persistent preferences for bonds of specific maturities issued by either the home or the foreign country. Such segmentation arises naturally from institutional mandates, regulatory constraints, or risk management practices. In this setting, the degree of substitutability between domestic and foreign bonds plays a critical role in determining the strength of international monetary policy spillovers—a fact underscored by the empirical patterns documented in Section 2.

Preferred habitat investor demand for country $j \in \{H, F\}$ bonds of maturity τ at time t takes the form:

$$Z_{jt}^{(\tau)} = -\alpha_j(\tau) \log P_{tj}^{(\tau)} - \beta_{jt}^{(\tau)}.$$

Here, the slope parameter $\alpha_j(\tau)$ governs the elasticity of bond demand. When $\alpha_j(\tau)$ is large, investors are relatively insensitive to price, consistent with strong preferences for particular maturities or issuers. Conversely, smaller values of $\alpha_j(\tau)$ imply more elastic demand and greater willingness to reallocate portfolios in response to changes in relative yields.

The intercept term $\beta_{jt}^{(\tau)}$ captures time-varying shifts in bond demand due to macroeconomic or financial conditions. We assume it evolves as:

$$\beta_{jt}^{(\tau)} = \zeta_j(\tau) + \theta_j(\tau)\beta_{jt},$$

where policy shocks—including unconventional monetary policy (UMP)—enter through β_{jt}.

While GRV treat the demand slopes $\alpha_j(\tau)$ as fixed, we extend their framework by allowing $\alpha_j(\tau)$ to vary. Economically, this reflects changes in the "specialness" of bonds—particularly U.S. Treasuries, in our case—which can shift over time due to liquidity, regulatory treatment, or market conditions. When Treasuries are perceived as particularly safe, liquid, and/or pledgeable, demand is relatively inelastic. When those attributes erode, the marginal investor becomes more price-sensitive, and spillovers from foreign monetary policy become more pronounced.

The notion that these demand slopes should be time-varying is not axiomatic. From the perspective of Vayanos and Vila (2021b) this slope function represents relative substitutability between bonds of a given maturity and a private investment opportunity priced in the utility function. These represent non-pecuniary characteristics of bonds which command a premium. We interpret this parameter as reflective of the convenience yield of Treasuries which, as documented in Figure 3, is time-varying. Therefore, to quantify the effects of a changing convenience yield on the sensitivity of Treasuries to exogenous shocks it suffices to examine a time-varying $\alpha_j(\tau)$. We treat the demand slopes as exogenously determined in line with the literature, testing the implications of their exogenous variation. This is similar in spirit to the "safety shock" notion of Kekre and Lenel (2024).

Of course, the non-pecuniary benefits of the convenience yield are not limited to preferred habitat investors. Global arbitrageurs will also value these characteristics to some degree. Following Greenwood et al. (2024) in modeling the convenience yield as additive in the arbitrageurs' objective function makes clear that a time-varying convenience yield will shift the level of the yield curve at all maturities. However, the manner in which this changes the yield curve's sensitivity to demand shocks β_{jt} is nontrivial and left as a subject for future research.[8] For now we will assume only the preferred habitat investors value the benefits of the convenience yield.

We formalize this idea by examining how the bond price $\log P_{jt}^{(\tau)}$ responds to small perturbations in the demand elasticity function $\alpha_k(\tau)$ for $k \in \{H, F\}$, holding other structural features constant. We focus on the mixed Gâteaux differential with respect to α_k and an economic shock vector $b_t = (i_{Ht}, i_{Ft}, \gamma_t, \beta_{Ht}, \beta_{Ft})^\dagger$, where † denotes transposition. For a fucntional perturbation direction $\phi_k(\tau)$ and shock impulse h , the differential

$$\left(\partial^2_{\alpha_k,b} \log P_{jt}^{(\tau)}\right)[\phi_k, h]$$

captures how yield sensitivity to shocks evolves when elasticity changes. We build this object constructively in the following manner.

We begin by isolating the simpler effect of an elasticity perturbation on bond prices, holding shocks fixed. Assuming a log-affine structure:

$$\log P_{tj}^{(\tau)} = -a_j(\tau)^\dagger q_t - c_j(\tau),$$

where $a_j(\tau) \in \mathbb{R}^5$ and $c_j(\tau) \in \mathbb{R}$ depend on structural parameters, the following holds:

Definition 3.1. The Gâteaux differential of the yield curve with respect to demand slopes is:

$$\sum_{k\in\{H,F\}} \partial_{\alpha_k} \log P_{jt}^{(\tau)} = - \sum_{k\in\{H,F\}} \left(\partial_M a_j(\tau)\right)^\dagger \cdot \partial_{\alpha_k}\mu \cdot q_t + \partial_M c_j \cdot \partial_{\alpha_k}\mu + \partial_{\alpha_k} c_j,$$

where M is an implicitly defined matrix functional capturing general equilibrium pricing relationships across assets and maturities.

The first term, involving $\partial_M a_j(\tau)$, reflects how the sensitivity of yields to shocks changes as investor elasticity evolves. Economically, $a_j(\tau)$ describes the exposure of bond yields to

[8] Greenwood et al. (2024) also show that under particular parameterizations this framework is isomorphic to one where arbitrageurs face balance sheet constraints.

structural shocks such as monetary policy interventions. Changes in elasticity alter this exposure indirectly, by shifting the underlying equilibrium encoded in M. The following proposition makes this relationship explicit.

Proposition 3.1.

$$\partial_M a_j(M,\tau) = \left[\tau e^{-\tau M} - \left(I - e^{-M\tau}\right) M^{-1}\right] \left(M^{-1} e_j\right) \left(M^{-1} e_j\right)^{\dagger}$$

where $e_j,\ j \in \{1,2\}$ is the j'th basis vector in $\mathbb{R}^5$.

Proof. See Appendix A.1 □

We must also characterize how M itself changes in response to elasticity shifts. The matrix M is defined implicitly as the fixed point of an equilibrium condition that aggregates investor demand, arbitrage constraints, and pricing relationships across maturities. Determining its variation requires applying the implicit function theorem in a Banach space. The result is stated below.

Proposition 3.2. The matrix M may be described locally as a functional of $\{\alpha_H(\tau), \alpha_F(\tau)\} \in C^b(\mathbb{R}) \times C^b(\mathbb{R})$, the union of Banach spaces of bounded functions:

$$M = \mu\left(\alpha_H(\tau), \alpha_F(\tau)\right)$$

in a neighborhood U_1 of some $\alpha_1^0(\tau)$ and U_2 of some $\alpha_2^0(\tau)$ such that the mapping

$$\mu : U_1 \times U_2 \to \mathbb{M}_{5\times 5}$$

is continuous C^1.

Proof. See Appendix A.2 □

Given the implicit function theorem applies, we can calculate the implicit differential. This differential is a matrix-valued functional.

Proposition 3.3.

$$\sum_{k=1}^{2} \partial_{\alpha_k} \mu = -\left\{ I + (\partial_M Y + \partial_M Z) \, Q \right\}^{-1} \times$$
$$\left\{ \sum_k \left[\int_0^\infty \left(I - e^{-M\tau} \right) (M^{-1} e_k) \left[\left(I - e^{-M\tau} \right) (M^{-1} e_k) \right]^\dagger \phi_k(\tau) \, d\tau \right] \right\} Q \tag{2}$$

where the functionals Y and Z are described in Appendix A.3 and $\phi_k(\tau)$ is the functional perturbation.

Proof. See Appendix A.3 □

This expression characterizes how the equilibrium object M—which governs the mapping from structural shocks to yield sensitivities—responds to changes in demand elasticity. Mathematically, this involves differentiating an implicitly defined matrix-valued function with respect to an infinite-dimensional object (the elasticity function $a_k(\tau)$). The result reflects the full general equilibrium adjustment to a shift in investor substitutability. Economically, it shows how a marginal relaxation in the "preferred habitat" assumption—whereby more investors become willing to substitute across maturities or across borders—reshapes the structure of yield sensitivities and, consequently, the transmission of monetary policy shocks.

We now turn to the dynamic implications of an elasticity shift. While the previous results describe how the yield curve responds contemporaneously to shocks when the elasticity function changes, understanding how those effects evolve over time is critical for evaluating monetary policy transmission. In practice, bond market adjustments to monetary shocks are not instantaneous; they unfold over time as expectations, arbitrage flows, and portfolio reallocations adjust.

In our model, the term structure dynamics are governed by a mean-reverting process for the state vector q_t, which captures the macroeconomic and policy-relevant determinants of yields. Specifically, we assume:

$$dq_t = \Gamma(\bar{q} - q_t) \, dt + \Sigma \, db_t$$

where $\Gamma \in \mathbb{R}^{5\times5}$ determines the rate at which q_t reverts to its long-run mean $\bar{q}$, and $\Sigma \in \mathbb{R}^{5\times5}$

determines how shocks propagate into the pricing factors.

Although our framework can accommodate multiple sources of heterogeneity across maturities, countries, and policy types, we focus on a stylized scenario to illustrate the mechanism: a one-time shock $db_t \in \mathbb{R}^5$ arrives at time t, during a period when investors in the home country (e.g., the U.S.) have become more price-sensitive due to a decline in the convenience yield of Treasuries. The direction of the elasticity shift is captured by the function $\phi_H(\tau)$, which can be interpreted as a maturity-specific perturbation to the demand curve slope—sharpened, for example, around the 10-year point if investors are especially sensitive to intermediate-term rates. This setting allows us to isolate the effects of a plausibly sized and empirically motivated change in elasticity on the transmission of a well-identified policy intervention.

To quantify how the effects of this shock evolve over time and across maturities, we follow the Malliavin calculus approach of Borovicka et al. (2014), which allows us to compute the path-wise derivative of the yield curve response. Our goal is to trace the difference in the impulse response function (IRF) of $\log P_{js}(\tau)$ at future dates $s \geq t$, conditional on the initial shock and the contemporaneous shift in investor elasticity.

Theorem 3.1. The sensitivity of the yield curve in period $s \geq t$ to a policy shock $db_t \in \mathbb{R}^5$, in country $j \in \{H, F\}$, given a perturbation of the elasticity function $\alpha_H(\tau)$ in the direction $\phi_H(\tau)$, is given by:

$$\partial^2_{\alpha_H, b} \log P^{(\tau)}_{js} = db_t \cdot \left\{ \Phi(\tau)^\dagger \left[I + \exp\{-(s-t)\Gamma\} \right] \Sigma \right\}, \tag{3}$$
$$\Phi(\tau) = \partial_M a_j(M, \tau) \cdot \partial_{\alpha_H} \mu$$

Proof. See Appendix A.4. □

This expression can be interpreted as the marginal change in the impulse response function due to a shift in investor elasticity. It captures how the pass-through from policy shocks to the yield curve strengthens (or weakens) when price sensitivity changes. The result consists of two components, each with a clear economic meaning.

The first term, $db_t \cdot \Phi(\tau)^\dagger \Sigma$, captures the instantaneous amplification of the yield curve response. When investors are more willing to reallocate in response to small price changes—i.e., when the demand curve is flatter—policy shocks trigger a larger immediate adjustment in bond prices. This term reflects how a local elasticity shift modifies the initial magnitude of the IRF at time t.

The second term, $db_t \cdot \Phi(\tau)^\dagger \exp\{-(s-t)\Gamma\}\Sigma$, captures the intertemporal propagation of the shock in expectation. Even after the initial period, the consequences of the elasticity shift persist: a more elastic investor base continues to amplify the effect of earlier policy shocks as they reverberate through the system. This term shows that elasticity not only shapes the initial adjustment, but also the dynamic multiplier governing the long-run impact of monetary policy.

Both effects are mediated by $\Phi(\tau)$, which is determined by the sensitivity of the yield exposure $a_j(\tau)$ to equilibrium conditions, and the sensitivity of those conditions to changes in elasticity. As shown in Propositions 3.1 and 3.3, this object encapsulates how general equilibrium pricing structures transmit micro-level changes in investor preferences into macro-level yield adjustments.

Together, these results offer a flexible, tractable framework for evaluating how variation in Treasury convenience affects the potency of cross-border monetary policy spillovers. When price elasticity rises—due to reduced specialness or changes in regulation—the transmission of both conventional and unconventional policy becomes more forceful, persistent, and broad-based across the term structure.

The following theorem notes that changing the demand curve slope also has a direct impact on the yield curve unrelated to the policy shocks. While not of direct interest to this paper, this does deliver additional testable hypotheses for future research.

Theorem 3.2. The yield curve responds directly to a change in demand curve slopes according to

$$\partial_{\alpha_k} c_j(\tau) = \partial_M c_j(\tau) \times \partial_{\alpha_k}\mu + \partial_{\alpha_k} c_j(\tau) \tag{4}$$

Where the individual components are non-trivial and given in Appendix A.5 along with the proof.

3.2 Calibration and Implications

We calibrate the model using parameters aligned with Table 1 in Gourinchas et al. (in press).[9] For parameters that enter the likelihood function only through multiplicative combinations, we proceed as follows. The coefficient of absolute risk aversion for global arbitrageurs is fixed at 10, consistent with the lower bound of GRV's estimates. This choice governs the sensitivity of arbitrageurs to relative returns across segmented bond markets. We then estimate the parameters θ_0 and θ_e, which govern the intercepts of bond and currency demand, by numerically minimizing the level set defined in Equation 13. The resulting values are $\theta_0 = 0.018$ and $\theta_e = 0.0021$. These fully determine the matrix functional M, which encapsulates the equilibrium mapping between structural parameters and yield curve coefficients.

To examine how investor price elasticity shapes the transmission of foreign monetary policy, we impose two assumptions designed to reflect stylized facts about the U.S. Treasury market and ECB policy implementation:

1. We treat the home country as the United States, and assume that the convenience yield on U.S. Treasuries has declined—either due to elevated net issuance, a reduction in Federal Reserve holdings, or tightening in balance sheet capacity among intermediaries. As a result, investors become more price-sensitive. We model this by perturbing the demand slope $\alpha_H(\tau)$ downward using a smooth function $\Phi_H(\tau)$.[10] This yields a new demand slope:

$$\alpha^*_H(\tau) = \alpha_H(\tau) - \epsilon \Phi_H(\tau)$$

   for a small ϵ, representing a moderate shift in elasticity focused in the belly of the curve.

2. We treat the foreign country as the Euro Area, and impose a stylized quantitative easing (QE) shock. Following GRV, we assume a bond purchase program concentrated at the 5-year maturity, amounting to 10% of euro area GDP. This generates a bond demand shock:

$$db_t = (0, 0, 0, 0, 1)^\dagger,$$

[9] Such parameter estimates are the result of a complicated maximum likelihood estimation routine. The reader is encouraged to consult Gourinchas et al. (in press) for specific details.

[10] Specifically, we use a transformed Cauchy distribution centered at the 10-year maturity with dispersion parameter 3, normalized to integrate to one.

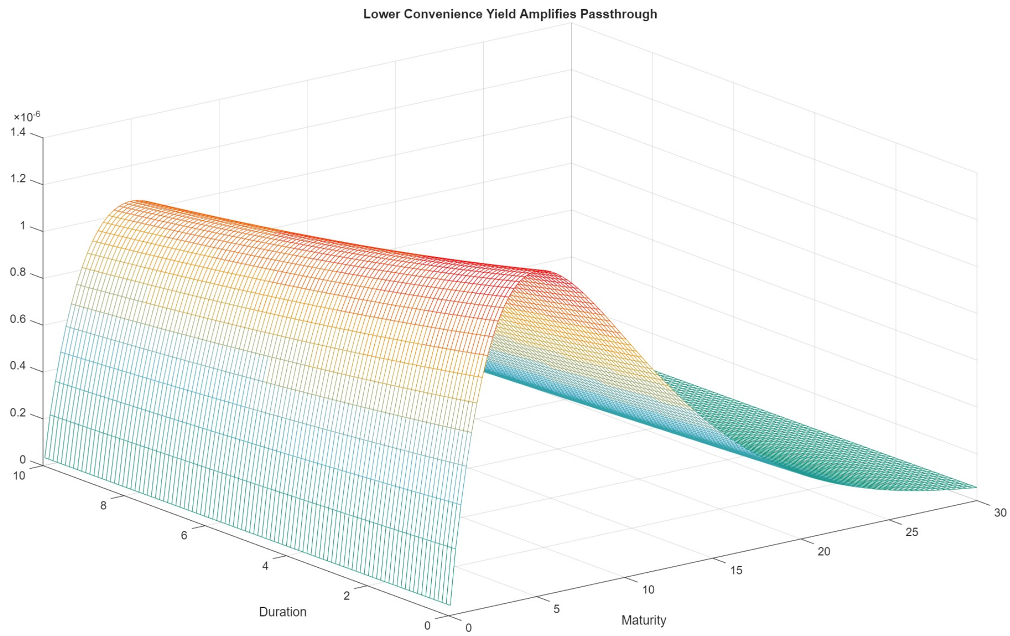


Figure 4: A plot of $\partial^2_{\alpha_H,b} \log P_{Hs}(\tau)$ given the perturbation function described in Assumption 1. Values describe the relative change in the impulse response function for the home yield curve following a foreign QE shock. Positive values indicate that the response is larger under greater price elasticity or lower convenience yield.

which is propagated across maturities using an exponential decay centered at 5Y.

Figure 4 displays the marginal effect of the elasticity perturbation on the impulse response of the U.S. yield curve to the foreign QE shock. Each surface point corresponds to a pair (τ, s), representing maturity and horizon respectively. The plotted values reflect $\partial^2_{\alpha_H,b} \log P_{Hs}(\tau)$: the change in the yield response at maturity τ and future period s, attributable to a local decline in investor price insensitivity. Three key results emerge, from which we draw testable hypotheses:

First, greater investor elasticity amplifies international spillovers across the entire yield curve. At nearly every maturity and horizon, the response of U.S. bond prices to the foreign QE shock is more positive following the decline in the convenience yield. This reflects the basic comparative statics: as investors become more responsive to yield differentials, they reallocate more aggressively in response to foreign shocks, and U.S. bonds become more substitutable. This pattern holds across short, intermediate, and long maturities, indicating that the elasticity shift induces a broad-based intensification of cross-border monetary transmission, not one confined to a particular segment of the yield curve.

Second, the amplification effect is most pronounced around the 5-year maturity and during the first few periods after the shock. This is not coincidental: the ECB's QE purchases are concentrated between 5 and 10 years, and the demand perturbation is targeted at the 10-year point—producing a region of the yield curve where substitution pressures are most acutely aligned. The result is a band of concentrated spillover amplification in the intermediate range. These interactions between the policy's maturity profile and the location of the elasticity shift underscore the importance of match between foreign intervention and domestic investor responsiveness. When the policy shock and the elasticity change are aligned along similar tenors, the amplification is strongest.

Third, the effects are persistent. Even as time $s - t$ increases, the marginal impact of the elasticity shift remains positive. This reflects the dynamic multiplier effect characterized in Theorem 3.1: the elasticity shift not only amplifies the initial response to a foreign policy shock, but also extends the influence of that shock over time. This persistence is a direct consequence of how investor preferences enter the term structure recursively through the dynamics of q_t.

Taken together, the calibration exercise demonstrates how changes in Treasury convenience can endogenously modulate the strength of cross-border monetary transmission. A less "special" Treasury market does not merely affect domestic yield levels—it alters the slope of the global demand schedule for U.S. bonds, steepening the international price response. During such periods, the effects of foreign monetary interventions become stronger, longer-lasting, and more sensitive to maturity structure.

To fix ideas, the following provides four testable hypotheses from the model which we will examine in subsequent empirical sections. Consider the following regression model for changes in the US Treasuries yield curve where MP is a monetary policy surprise, CV is a proxy measure of the convenience yield, h is the horizon of impact in calendar days, N is the average maturity of ECB purchases, and X_t is a set of controls:

$$\Delta y^{(n)}_{US,t:t+h} = \alpha + \beta_1 X_t + \beta^h_2 MP^{ecb}_t + \beta^h_3 CV^{(n)}_{US,t-1} \times MP^{ecb}_t + \epsilon^n_t \tag{5}$$

Hypothesis 1. $\beta_3^0 > 0$.

Theorem 3.1 states that a more elastic demand curve, which follows from a diminution of U.S. Treasuries' non-pecuniary characteristics, amplifies the instantaneous spillover from ECB bond purchases. Thus, it follows from Theorem 3.1 that $\beta_3^0 \neq 0$. The calibration of the model from Figure 4 fix the expected sign of the interaction coefficient $\beta_3^0 > 0$. Note that $\beta_2^0 > 0$ follows directly from GRV, provided that the the ECB is operating under the ELB.

Hypothesis 2. $\beta_3^h > 0$ for $h = \{1, \ldots, H\}$

From Theorem 3.1, local projections from monetary policy surprises should display amplification and persistence through time which is maturity-specific.

Hypothesis 3. β_3^h is maximized in a neighborhood of N.

It follows from the calibration of Figure 4, which is itself informed by the institutional background of ECB purchases, that unconventional monetary policy spillovers should predominantly affect the long end of the yield curve, peaking near the maturities targeted by the ECB (5 - 10 years).

As a caveat to our chosen set-up, there is a large literature concerning the drivers of the convenience yield. Many of these drivers are endogenous macroeconomic quantities which suggest variation in the convenience yield, and therefore $\alpha_k(\tau)$, should not be thought of as exogenous variation. The benefit of defining these comparative statics such as in Theorem 3.1 with functional derivatives and Malliavin calculus is that this endogeneity can be easily accounted for with an extra functional chain rule term at the end of $\Phi(\tau)$. For instance $\partial_q \alpha_H$ if such a functional derivative is known to the model.

3.3 Asynchronous Monetary Policy Under Lower Convenience Yield

We extend the previous exercise by introducing an additional shock to capture a period of policy asynchronicity. Specifically, we consider a scenario in which the foreign country (the Euro Area) undertakes quantitative easing, while the home country (the United States) simultaneously tightens monetary policy through a conventional rate hike. This configuration mirrors the episode in which the Federal Reserve initiated policy normalization while the European Central Bank remained accommodative.

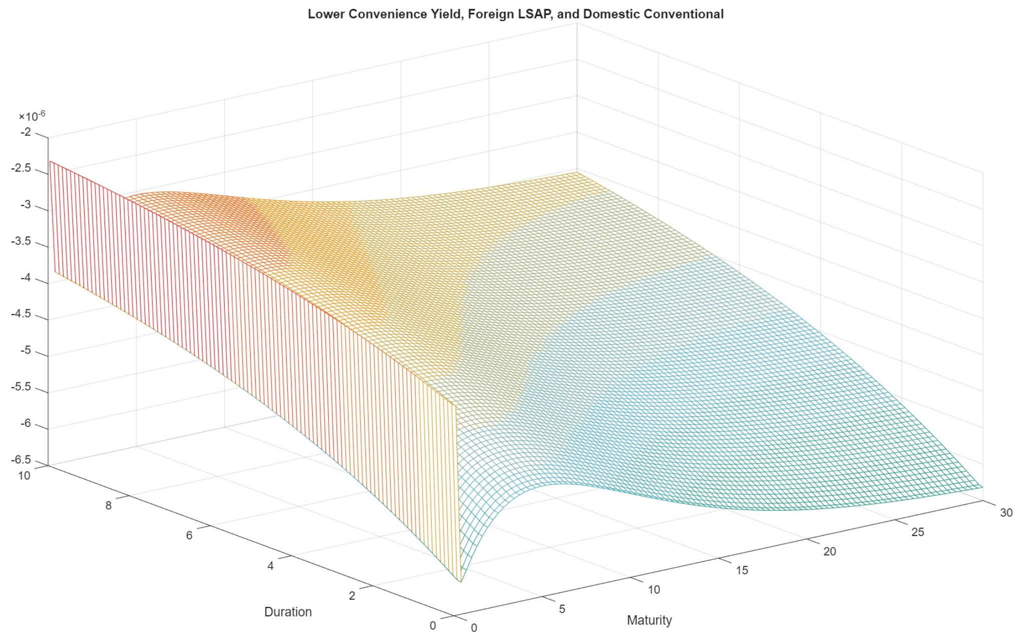


Figure 5: A plot of $\partial^2_{\alpha_H,b} \log P_{Hs}(\tau)$ given the perturbation function described in Assumption 1. Values describe the relative change in the impulse response function for the home yield curve in response to a simultaneous home rate hike and foreign QE shock. Positive values indicate a larger response under increased investor elasticity.

We maintain the assumptions from Section 3.2 regarding the elasticity shift: the convenience yield on U.S. Treasuries has declined, making investors more price-sensitive, and the demand slope $\alpha_H(\tau)$ is perturbed in the direction $\Phi_H(\tau)$ as before.

We now introduce a second shock to reflect a contractionary policy action in the U.S. Specifically, we modify the shock vector to:

$$db_t = (1, 0, 0, 0, 1)^\dagger,$$

which combines a short-rate tightening in the home country with a QE shock in the foreign country. The QE component retains the same profile used in the prior exercise: a bond purchase program concentrated at the 5-year maturity and amounting to 10% of GDP.

Figure 5 illustrates the resulting impulse response differentials across maturities and horizons. These values represent how the joint response of the yield curve to opposing policy actions changes when U.S. investors become more price-sensitive. Several key findings emerge:

First, the elasticity shift systematically attenuates the contractionary effect of home monetary tightening. Although the home short rate increases, the simultaneous foreign QE induces capital inflows that partially offset the tightening. When investors are more elastic, these inflows are larger and more persistent. The net result is a smaller upward shift in yields than would occur in the absence of the elasticity shift.

Second, the attenuation is especially pronounced at intermediate and long maturities. This reflects the interaction between the short-term nature of conventional policy and the duration-targeted nature of QE. Even when home policy raises short rates, more elastic investors continue reallocating toward longer-term U.S. bonds in response to foreign purchases. The result is a dampened policy passthrough at the long end of the curve.

Third, the effects are persistent across horizons. The relative dampening of the yield response continues even several periods after the initial shock. This persistence mirrors the dynamic structure of Theorem 3.1, and reflects how lower convenience amplifies the influence of foreign accommodation while diminishing the effectiveness of domestic tightening.

Taken together, these results highlight a novel constraint facing central banks during periods of policy divergence. When domestic bonds lose their convenience premium, the capacity to offset foreign monetary expansion is weakened. Conventional policy becomes less effective—not because it fails to move the short rate, but because the global investor base reallocates around it. In such environments, restoring monetary independence may require more forceful or coordinated policy action.

These findings may help rationalize a puzzling episode in recent U.S. yield curve dynamics. In August 2019, the U.S. yield curve inverted, with 10-year Treasury yields falling below short-term rates, despite a robust domestic labor market and positive GDP growth. At the time, the Federal Reserve had begun raising short rates as part of its policy normalization cycle, while the ECB was still engaged in accommodative monetary policy at the ELB. From the perspective of our model, this outcome is not anomalous: a contractionary shock to the home short rate, when layered on top of ongoing foreign QE and a contemporaneous decline in Treasury convenience, can result in attenuated or even reversed yield curve responses. More elastic investors, facing a flatter demand curve, shift into longer-term Treasuries as their relative yields remain attractive in a global context. The result is an inversion driven not by recession expectations, but by asymmetric monetary policy and a time-varying convenience premium affecting the reallocation decision of investors.

3.4 Exchange Rate Risk

Whereas the foreign exchange market is not the focus of this paper, it is worth noting that the model provides testable hypotheses for the changing sensitivity of the exchange rate to policy shocks. The following theorem summarizes:

Theorem 3.3. Given the log-affine function for the exchange rate derived in Gourinchas et al. (in press):

$$log\ e_t = -a_e^{\dagger} q_t - c_e + (\pi_H - \pi_F)t \tag{6}$$

$$M a_e = e_1 - e_2 \tag{7}$$

Where e_1 and e_2 are the first two columns of the I_5 identity matrix.
The sensitivity of the log exchange rate in period $s \geq t$ to a policy shock $db_t \in \mathbb{R}^5$, given a perturbation of the elasticity function $\alpha_k(\tau)$ in the direction $\phi_k(\tau)$ for $k \in \{H, F\}$, is given by:

$$\begin{aligned} \partial^2_{\alpha_k, b} \log e_t &= db_t \cdot \left\{ \Phi_e(\tau)^{\dagger} \left[I + \exp\{-(s-t)\Gamma\} \right] \Sigma \right\}, \\ \Phi_e(\tau) &= M^{-1}(\partial_{\alpha_k} \mu) a_e \end{aligned} \tag{8}$$

Proof. Nearly identical to that of Theorem 3.1. □

4 The Portfolio Balance Channel of Spillovers

We evaluate the mechanisms laid out in the model by conditioning the impact of ECB spillovers to the U.S. yield curve on Treasury (in)convenience. We begin by regressing various segments of the term structure on intradaily ECB monetary policy shocks, interacting the shocks with the level of the convenience yield in the U.S. and in Germany. We use the swap spread on Bunds to proxy for Euro area convenience because they are the closest match to U.S. Treasuries in terms of their non-pecuniary qualities. Regressions take the following form:

$$\Delta y_{US,t}^{(n)} = \alpha + \beta_1 SS_{US,t-1}^{(n)} + \beta_2 MP_t^{ecb} + \beta_3 MP_t^{ecb} \times SS_{US,t-1}^{(n)} + \beta_4 MP_t^{ecb} \times SS_{DE,t-1}^{(n)} + \\ ... + \beta_5 SS_{DE,t-1}^{(n)} + \gamma_1 PR_{t-1} + \gamma_2 (y_{US,t-1}^{n} - y_{EU,t-1}^{(n)}) + \epsilon_{it} \quad (9)$$

As in Figure 3, convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap; however, to orient the interpretation toward "inconvenient" Treasuries or Bunds, we express the spread as the sovereign yield less OIS—when the Treasury yield rises relative to OIS, Treasuries have become less convenient. $SS_{EU,t-1}^{(n)}$ and $SS_{US,t-1}^{(n)}$ are the n-year swap spreads for Germany and the U.S. ($y_{i,t-1}^{n} - y_{i,t-1}^{ois,n}$), expressed in z-scores, and $y_{US,t}^{(n)}$ is either the yield on the n-year Treasury bond, the n-year term premium, or the expected path of short rates over an n-year horizon. Convenience yields and any daily control variables enter as the previous day's value, given that convenience yields, Treasury yields, and policy rates are simultaneously determined on announcement days. So, while t indexes ECB announcement days, $t-1$ refers to the calendar day before an announcement.

We follow the standard practice of controlling for the policy rate in each respective market, as convenience yields and policy rates tend to be highly correlated (Nagel (2016)). In regressions conditioning on Treasury convenience, PR_{t-1} is the fed funds rate, and when conditioning on the convenience yield of Germany, the ECB's policy rate stands in. In some specifications we include the spread between maturity-matched Treasury and European zero coupon yields to account for the raw return differential.[11] This allays the valid concern that investors could be dissuaded from substituting into Treasuries from European bonds due solely to a divergence in their returns. To avoid excessive influence of outliers, we estimate parameters by robust regression, using an M-estimator as in Rogers et al. (2014).

Table 2 and Figure 6 display and summarize the results. Because spillovers are concentrated, both theoretically and empirically, at the longer end of the yield curve, we focus first on estimates for the decomposition of the 10-year yield. Table 2 shows the impact on 10 year yields of a one standard deviation monetary policy shock from the ECB, conditional on the

[11] Euro area yield curve data can be accessed on the ECB website, which we accessed through Haver.

Table 2: Spillovers to the 10 year Treasury yield, conditional on convenience yields

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Y_{10}	Y_{10}	Y_{10}	Y_{10}	Y_{10}	Y_{10}	TP_{10}	SR_{10}
ECB	2.90***	3.84***	3.73***	4.28***	4.44***	3.26***	2.17***	1.66***
	(0.82)	(0.88)	(0.89)	(1.00)	(1.00)	(0.96)	(0.68)	(0.46)
Y^{us}_{10} - Y^{eu}_{10}					-1.30	-1.24		
					(1.19)	(1.19)		
FFR_{t-1}			-0.44	-0.32	0.18	0.17	-0.38*	0.05
			(0.32)	(0.33)	(0.55)	(0.55)	(0.22)	(0.15)
MRO_{t-1}			-0.13		-1.13	-1.02		
			(0.54)		(0.94)	(0.94)		
Swap spread$^{US}_{10}$		0.55*	-0.36	-0.09	-0.34	-0.09	-0.42	0.24
		(0.34)	(0.95)	(0.62)	(0.95)	(0.95)	(0.42)	(0.29)
Swap spread$^{EU}_{10}$				0.91**	0.70	0.75*	0.38	0.34*
				(0.40)	(0.44)	(0.45)	(0.27)	(0.18)
ECB × Swap spread$^{US}_{10}$		1.78**	1.74**	1.64**	1.62**		0.97**	0.35
		(0.72)	(0.73)	(0.72)	(0.72)		(0.49)	(0.33)
ECB × Swap spread$^{EU}_{10}$				0.61	0.72		0.88*	-0.26
				(0.76)	(0.77)		(0.52)	(0.35)
ECB × Y^{us}_{10} - Y^{eu}_{10}						0.28		
						(1.06)		
Constant	0.53	0.62	1.61	1.13*	3.15*	2.87	1.21***	-0.02
	(0.38)	(0.38)	(1.08)	(0.68)	(1.83)	(1.83)	(0.46)	(0.31)
Observations	265	259	259	259	259	259	259	259

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2 displays estimates regressing changes in 10-year U.S. zero coupon bond yields, term premia, and expected path of short rates on ECB monetary policy surprises, conditional on the lagged level of Treasury and Bund convenience yields. Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, 5-, 10-year German and French bond yields. Surprises are normalized to raise two year Euro OIS by 10 basis points. Convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap ($Y - OIS$) and are normalized to have zero mean and unit variance. An increase in this proxy reflects a decrease in convenience. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

convenience yields on Treasuries and Bunds. Columns 2 - 5 show spillovers to the yield conditioning on the level of the term premium including and excluding various controls, while column 6 shows results conditioning on the Treasury-Bund spread instead of convenience yields.

In line with Hypothesis 1, positive parameter values in columns 2 - 5 show that the degree to which a loosening shock from the ECB pulls down longer-term Treasury yields rises when the convenience yield on Treasuries wanes, or when yields rise relative to maturity-matches OIS ($\beta_2 > 0$ and $\beta_3 > 0$). Across columns, the magnitude is remarkably consistent between specifications. Focusing on the most conservative specification in column 5, when convenience yields are at average levels (i.e., its z-score is equal to zero), a loosening by the ECB that lowers 24-month Euro OIS by 10 basis points reduces 10 year Treasury yields by 4.4 basis points. When the convenience yield is one standard deviation below the mean, the size of spillovers from the ECB expands by 1.64 basis points.

To give a sense of the economic significance of this difference, a one standard deviation change in 10 year Treasury yields in our sample is 5.86 basis points. A 4.4 basis point drop in 10 year yields (which corresponds to the size of the spillover when convenience yields are at their historical average) would fall in the bottom 20% of the unconditional distribution of Treasury yield changes. A 6.1 basis point drop, which corresponds to the estimated impact of the same sized loosening when the convenience premium is one standard deviation *below* historical average, would fall in the bottom 12% of the unconditional distribution. Notably, the convenience yield on Bunds does not appear to impact the size of spillovers to the U.S. yield curve. In some sense, this is unsurprising. ECB LSAPs included bonds according to their weight in the capital key, such that Bunds themselves are an incomplete representation of the portfolio characteristics requiring substitution in the event of LSAPs. In contrast to the results obtained from convenience yields, conditioning the impact of ECB shocks on the simple yield spread does not appear to alter the size of spillovers (column 6).

Turning to the yield decomposition in columns 7 and 8 shows that the change in the 10 year Treasury yield arises primarily through the term premium (col. 7), given that the parameter estimate on β_3 is positive and statistically significant for the term premium and not statistically different from zero for the expected path of short rates. A diminution of convenience yields, by increasing the substitutability between Bunds and Treasuries, contributes to an increase in spillovers to the U.S. 10 year term premium because displaced Bund investors increase their demand for Treasuries at a higher rate. This mechanism, both in theory and in the evidence presented in column 8, bears no relation to the expected path of short rates over a ten year horizon.

Figure 6: Spillovers to the 10 year Treasury yield, conditional on convenience yields

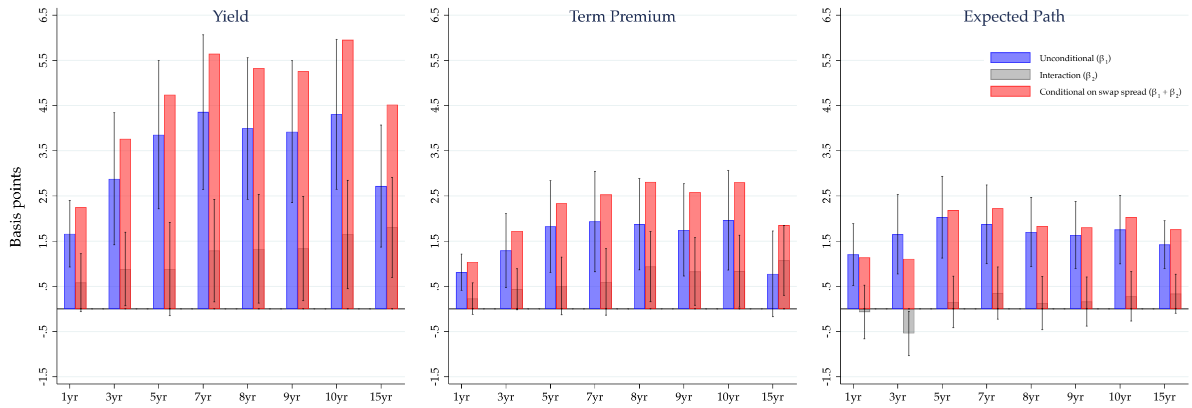


Figure 6 summarizes a series of regressions estimating changes in U.S. zero coupon bond yields, term premia, and expected path of short rates across the yield curve ECB monetary policy surprises, conditional on the lagged level of Treasury and Bund convenience yields. Control variable include the raw yield spread on n-year bonds, the lagged Fed funds rate, and the lagged Main Refinancing Operation rate. Monetary policy surprises comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, 5-, 10-year German and French bond yields. Surprises are normalized to raise two year OIS by 10BP. Convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap ($Y - OIS$) and are normalized to have zero mean and unit variance. An increase in this proxy reflects a decrease in convenience. Blue bars correspond to the unconditional impact of monetary policy shocks on the yield decomposition, while red bars show the impact of a one standard deviation ECB monetary policy surprise conditional on the convenience premium being one standard deviation below its historical average (base effect + interaction effect). Spikes within the red bars denote 90% confidence intervals surrounding the interaction term.

Figure 6 summarizes regression results across the yield curve, supporting the notion that these mechanisms are concentrated in longer maturities, in line with Hypothesis 2. Blue bars in the figure show parameter values (and 90% robust confidence intervals) associated with the impact of ECB monetary policy surprises when the convenience yield is at its historical average (β_2), while red bars show the impact of a one standard deviation monetary policy surprise conditional on the convenience yield being one standard deviation below its historical average ($\beta_2 + \beta_3$). The confidence intervals within the red bars correspond to the statistical significance of the interaction term, β_3, which tests whether the variation in spillovers conditional on changes in the convenience yield differ significantly from the unconditional impact. The left-most panel, which summarizes the impact of spillovers across the yield curve, suggests that as Treasury convenience fades, spillovers to Treasury yields grow, and this differential impact rises with the maturity of the Treasury bond until the 10-year tenor, waning thereafter.[12]

The middle and right panels display spillovers across maturities in the term premium and expected path of short rates. These estimates suggest that increased sensitivity in long term bond yields emerges primarily because the term premium responds more forcefully in the face of Treasury inconvenience. At the same time, we observe that the level of the convenience yield has no bearing on spillovers to the expected path of interest rates.

To assess the persistence of the spillover, we recast the baseline regression in a series of local projections. Figure 7 shows the cumulative reaction of 1- and 10-year yields and term premia to our ECB monetary policy surprises over a 60-day horizon. In blue is the spillover from an ECB monetary policy shock when the US convenience yield is at its average value. In red the same response conditions on a decrease in the US convenience yield by one standard deviation. Comparing the reaction of the two tenors affirms Hypothesis 3: spillovers at the end of yield curve show more persistence, and a waning in convenience is indeed associated with more persistent yield spillovers.

4.1 Policy Decomposition

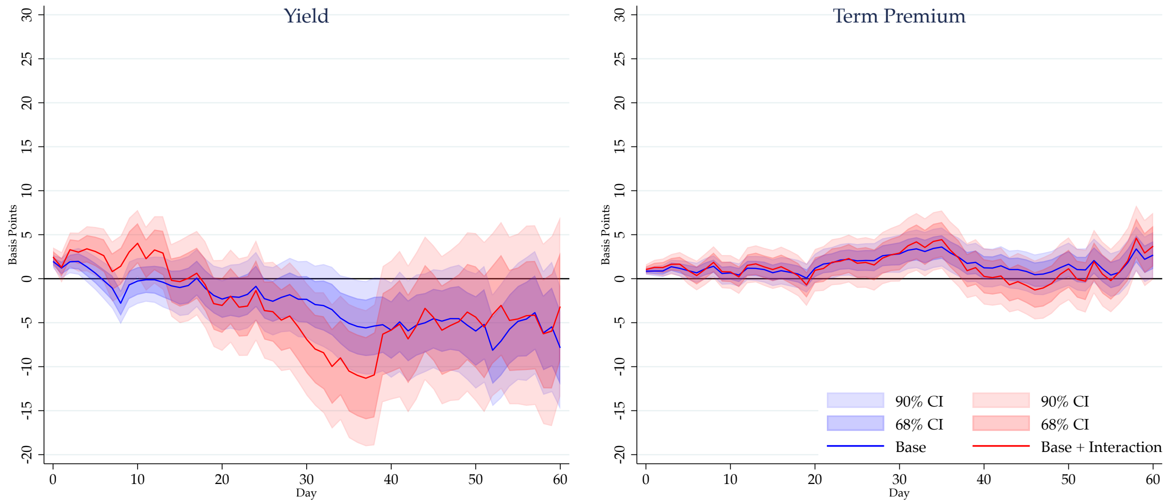
Our main analysis uses a measure of monetary policy designed to reflect the changing exercise of monetary policy over time, summarized by one variable. However, given the present focus on the differing mechanisms brought to bear by conventional versus unconventional monetary policy tools, it makes good sense to decompose the baseline results into long-rate-based and short-rate based tools as best we can. To that end, we follow Swanson (2021) in generating a three-part monetary policy shocks in the following manner.

First, we extract the surprise component of the decision about the target rate based on the change in yield on the three-month ahead OIS futures contracts on the dates of monetary policy announcements, which we label the "target surprise". Next, we take the residual from a regression of the announcement day change in the implied yield on the 24 month ahead futures contracts on the three-month Euro Interbank Offered Rate onto the target surprise and label this the "forward guidance surprise". Finally, we take the residual from a regression

[12] For maturities beyond 10 years, we report only the 15-year yield, as data for computing swap spreads at longer horizons are relatively sparse.

Figure 7: Dynamic spillovers to the 1- and 10-year Treasury yield, conditional on convenience yields

(a) 1-year



(b) 10-year

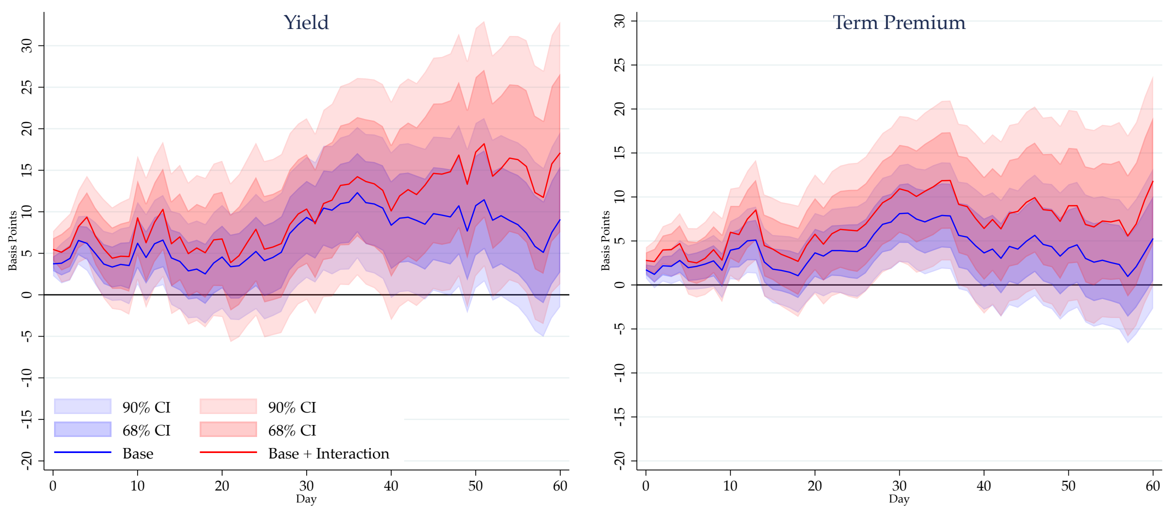


Figure 7 depicts the parameter values and confidence intervals from local projections of changes in the 1- and 10-year U.S. zero coupon yield on ECB monetary policy shocks, both unconditionally and conditional on the lagged level of Treasury convenience yields. Monetary policy surprises comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, 5-, 10-year German and French bond yields, normalized to raise two year OIS by 10BP. Convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap ($Y - OIS$) and are normalized to have zero mean and unit variance. An increase in this proxy reflects a decrease in convenience. The red lines and area show the impact of a one standard deviation ECB monetary policy surprise conditional on the convenience premium being one standard deviation below its historical average (base effect + interaction effect).

Table 3: Spillovers to the U.S. yield curve, by shock type

	Yield			Term Premium			Expected Path of Short Rates		
	(1) Y_1	(2) Y_5	(3) Y_{10}	(4) TP_1	(5) TP_5	(6) TP_{10}	(7) SR_1	(8) SR_5	(9) SR_{10}
Target EU	-0.15	0.96	0.81	0.55**	0.83	0.30	-1.63***	-0.61	-0.40
	(0.47)	(0.94)	(0.98)	(0.26)	(0.59)	(0.66)	(0.53)	(0.53)	(0.44)
Path EU	3.93***	7.04***	5.44***	-0.05	1.53*	1.33	4.54***	4.84***	4.15***
	(0.72)	(1.44)	(1.50)	(0.40)	(0.89)	(1.02)	(0.81)	(0.81)	(0.68)
LSAP EU	1.02	6.52*	11.65***	3.57***	8.84***	10.10***	-3.09	-1.81	0.37
	(1.88)	(3.73)	(3.90)	(1.03)	(2.32)	(2.64)	(2.11)	(2.09)	(1.75)
Constant	0.09	0.38	0.54	0.27***	0.51**	0.54**	-0.22	0.04	0.07
	(0.18)	(0.35)	(0.37)	(0.10)	(0.22)	(0.25)	(0.20)	(0.20)	(0.17)
Observations	268	268	268	268	268	268	268	268	268

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3 depicts the regressions associated with equation 10 where the dependent variables are the yields, term premia, and expected path of short rates for US Treasuries at the 1-, 5-, and 10-year maturity lengths. Regressors are the ”target surprise”, ”forward guidance surprise”, and ”LSAP surprise” monetary policy shocks generated according to Swanson (2021).

of the announcement day change in the French and German 10-year bond yields (summarized by their first principal component) onto the target and forward guidance surprises. This “LSAP surprise” is intended to capture changes in long-term interest rates that are associated with announcements related to large-scale asset purchases. As large scale purchases begin strictly after May 2009 (when the Securities Markets Programme was announced), we restrict this monetary policy surprise measure to equal zero before that date as in Swanson (2021) and Rogers et al. (2018). To ease the comparison between the components, these shocks are normalized by a factor consistent with increasing the baseline monetary policy measure by one unit.

With these measures in hand, we regress 1-, 5-, and 10-year yields, term premia and expected path of short rates on the three-part shock in the full sample. Regressions take the form:

$$Y_t^n = \alpha + \beta_1 target_t + \beta_2 path_t + \beta_3 lsap_t + X_t\Omega + \nu_t \qquad (10)$$

where X_t is a vector of controls including the lagged Fed funds rate, the lagged main refinancing operations rate, and the lagged spread between the n-year European zero coupon bond yield and the maturity-match U.S. Treasury zero coupon yield.

The results are displayed in Table 3. Unconditionally and in the full sample, path and LSAP shocks drive all detectable spillovers to U.S. yields. While path shocks impact both the expected path of short rates and term premia across the yield curve, LSAP shocks influence U.S. yields exclusively at higher maturities, and exclusively through the term premium. Consistent with the portfolio balancing channel of unconventional monetary policy, LSAP shocks play a larger role, which increases with maturity, in driving ECB spillovers to the term premium. As we expect, LSAP-type shocks have no statistically significant impact on the expected path of short rates.

Table 4 conditions the impact of the 3-part monetary policy shock on the inverse convenience yield ($y_n - OIS_n$). Although spillovers to yields themselves do not appear to change with shifts in Treasury convenience, appealing to the term premium uncovers the effect we expect to see—when the inconvenience of Treasuries increases, LSAP shocks generate larger spillovers to medium- and long-duration Treasuries.

4.2 Drivers of the Convenience Yield

Exploring the changing factors underlying the specialness of Treasuries offers additional insights about the changing nature of spillovers from unconventional monetary policy and helps to validate the properties of Treasuries as a key driver of the strength of spillovers. The literature on the Treasury's convenience yield offers competing (and complementary) views as to what it prices. This subsection explores some of the most commonly cited drivers underlying the changing convenience of Treasuries: net Treasury issuance, balance sheet constraints, and inflation risk.

A number of key contributions in this literature emphasize net supply of Treasuries in driving the convenience yield, showing that a relative increase in the supply of Treasury bonds makes them less special (Krishnamurthy and Vissing-Jorgensen (2012); Du et al. (2018)). Additional issuance, or the cessation of central bank purchases, eases the scarcity of sovereign bonds, thereby lowering convenience yields. Figure 8 bears this relationship out in striking fashion.

Table 4: Target, Path and LSAP Spillovers to the U.S. yield curve, conditional on $Y^n - OIS^n$

(a) Target

	Yield			**Term Premium**			**Expected Path of Short Rates**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Y_1	Y_5	Y_{10}	TP_1	TP_5	TP_{10}	SR_1	SR_5	SR_{10}
Target EU	-0.01	2.31*	1.98	0.74**	0.79	1.04	-1.17*	0.17	-0.03
	(0.53)	(1.19)	(1.22)	(0.30)	(0.74)	(0.83)	(0.60)	(0.67)	(0.56)
Tgt×Swap spread$_n$	1.35***	0.82	1.15	0.18	-0.01	0.61	0.75*	0.48	0.14
	(0.38)	(0.77)	(0.89)	(0.21)	(0.48)	(0.61)	(0.43)	(0.43)	(0.41)
Path	4.48***	7.41***	5.88***	0.11	1.52*	1.15	4.74***	4.78***	4.09***
	(0.72)	(1.43)	(1.49)	(0.40)	(0.90)	(1.01)	(0.82)	(0.81)	(0.68)
LSAP	0.64	5.00	10.49***	3.50***	8.26***	9.80***	-3.56*	-2.02	0.39
	(1.87)	(3.73)	(3.86)	(1.05)	(2.34)	(2.63)	(2.12)	(2.09)	(1.77)

(b) Path

	Y_1	Y_5	Y_{10}	TP_1	TP_5	TP_{10}	SR_1	SR_5	SR_{10}
Target EU	-1.01**	1.45	0.72	0.64**	0.81	0.33	-1.79***	-0.46	-0.16
	(0.49)	(0.95)	(1.00)	(0.27)	(0.60)	(0.68)	(0.53)	(0.54)	(0.46)
Path EU	3.66***	7.56***	5.87***	0.18	1.55*	1.30	3.66***	4.61***	4.06***
	(0.81)	(1.49)	(1.51)	(0.44)	(0.93)	(1.02)	(0.87)	(0.84)	(0.69)
Path×Swap spread$_n$	-1.58***	-1.35	-0.92	0.25	0.11	-0.04	-1.41**	-0.47	-0.32
	(0.59)	(1.06)	(1.47)	(0.32)	(0.67)	(1.00)	(0.64)	(0.60)	(0.67)
LSAP	1.80	6.36*	12.35***	3.38***	8.20***	10.17***	-2.29	-1.52	0.61
	(1.94)	(3.77)	(3.90)	(1.05)	(2.36)	(2.64)	(2.08)	(2.13)	(1.79)

(c) LSAP

	Y_1	Y_5	Y_{10}	TP_1	TP_5	TP_{10}	SR_1	SR_5	SR_{10}
Target EU	-0.49	1.19	0.64	0.62**	0.72	0.29	-1.63***	-0.47	-0.20
	(0.49)	(0.96)	(0.99)	(0.27)	(0.59)	(0.67)	(0.55)	(0.54)	(0.46)
Path	3.93***	7.86***	6.31***	0.02	1.51*	1.42	4.39***	4.80***	4.12***
	(0.74)	(1.44)	(1.48)	(0.41)	(0.89)	(0.99)	(0.82)	(0.81)	(0.68)
LSAP EU	0.39	0.31	-1.68	2.02	-1.14	-3.74	-1.14	-1.62	-1.60
	(3.06)	(8.85)	(9.85)	(1.68)	(5.48)	(6.60)	(3.39)	(4.98)	(4.52)
LSAP×Swap spread$_n$	1.91	6.24	16.59	4.20	10.57*	16.65**	-4.10	-0.25	2.65
	(5.50)	(9.70)	(11.89)	(3.02)	(6.01)	(7.97)	(6.09)	(5.46)	(5.46)
Observations	264	264	262	264	264	262	264	264	262

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4 depicts the regressions associated with equation 10 where the dependent variables are the yields, term premia, and expected path of short rates for US Treasuries at the 1-, 5-, and 10-year maturity lengths. Regressors are the "target surprise", "forward guidance surprise", and "LSAP surprise" monetary policy shocks generated according to Swanson (2021). Each panel contains one of the three monetary policy surprises interacted with a proxy for the convenience yield: the maturity-matched swap spread ($Y - OIS$), normalized to have zero mean and unit variance. An increase in this proxy reflects a decrease in convenience. All regressions include the lagged Fed funds rate, the lagged main refinancing operations rate, and the spread between the n-year European zero coupon bond yield and the maturity-match U.S. Treasury zero coupon yield.

Figure 8: Debt Supply and the Convenience Yield

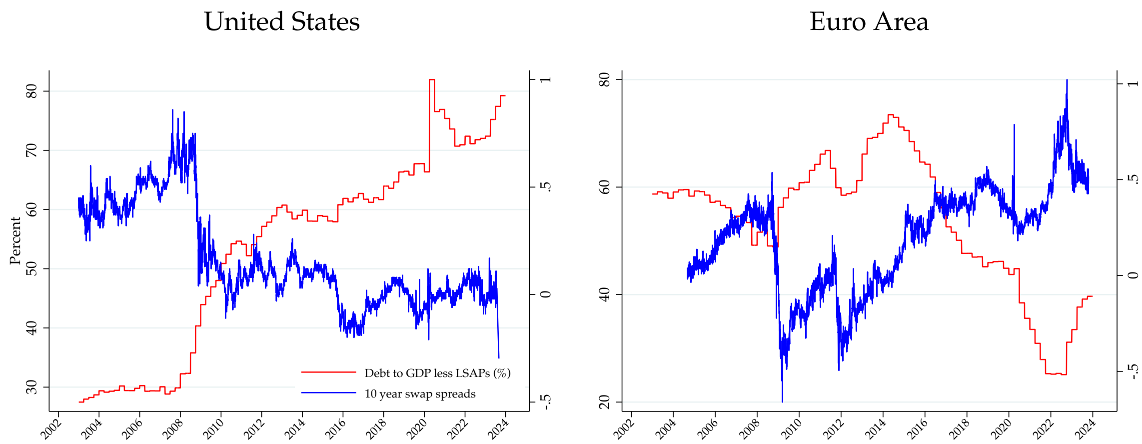


Figure 8 depicts government debt outstanding in the United States and in the Euro area as a percent of GDP, less holdings by the Fed and the ECB respectively, in red. Blue lines depict the 10 year swap spread on Treasuries and Bunds.

Linking debt supply to time variation in spillovers, Table 5 shows the impact of ECB monetary policy shocks conditioning on the previous quarter's outstanding sovereign debt (net of central bank purchases) as a percent of GDP, again controlling for the lagged level of the policy rate and the Treasury-Bund spread. Here again, we limit the results to 10-year yields to economize on space, although additional results appear in the appendix.

We see in each specification of Table 5 that spillovers to U.S. yields grow when the net supply of Treasuries rises. Column 5 suggests that a one standard deviation ECB monetary policy shock when U.S. debt outstanding (less Fed holdings) is at historical averages decreased the 10 year Treasury yield by 3.9 basis points. When the publicly available U.S. debt stock increases one standard deviation over historical average (about 7.6 percentage points), the impact of an ECB monetary policy shock rises by 50 percent (from 3.9 basis points to 5.35 basis points). Columns 6 - 7 suggest that this impact arises chiefly from term premia, although the point estimates are statistically insignificant. The full set of specifications can be found in Appendix Table 8.

Alternatively, a number of authors name inflation risk as a key driver of the convenience yield. We should expected to see larger spillovers through term premia when inflation expectations are less well-anchored because the stability of Treasuries' real value is a critical element supporting their special status, and thus the convenience premium. To test the relation-

Table 5: Spillovers to the 10 year Treasury yield, conditional on net bond supply

	(1) Y_{10}	(2) Y_{10}	(3) Y_{10}	(4) Y_{10}	(5) Y_{10}	(6) TP_{10}	(7) SR_{10}
ECB	2.90***	3.27***	3.35***	3.47***	3.87***	1.28**	2.26***
	(0.82)	(0.84)	(0.83)	(0.87)	(0.86)	(0.59)	(0.37)
Float/GDP (US)		0.14	-0.60	-1.08	-0.63	-0.17	-0.47
		(0.37)	(0.47)	(0.83)	(0.97)	(0.66)	(0.42)
FFR_{t-1}			-0.54**	-0.73**	0.46	-0.24	0.70***
			(0.22)	(0.29)	(0.56)	(0.38)	(0.24)
Y_{10}^{us} - Y_{10}^{eu}				0.37	-1.47	-0.21	-1.28**
				(0.79)	(1.16)	(0.79)	(0.50)
Float/GDP (EU)					0.24	0.19	-0.08
					(0.54)	(0.37)	(0.23)
ECB × Float/GDP (US)		1.70**	1.67**	1.80**	1.48*	0.45	-0.12
		(0.82)	(0.81)	(0.86)	(0.86)	(0.59)	(0.37)
MRO_{t-1}					-1.41	0.17	-1.58***
					(0.88)	(0.60)	(0.38)
Constant	0.53	0.56	1.59***	1.53**	3.40**	0.93	2.41***
	(0.38)	(0.38)	(0.55)	(0.65)	(1.61)	(1.10)	(0.70)
Observations	265	265	265	259	229	229	229

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5 displays estimates regressing changes in 10-year U.S. zero coupon bond yields, term premia, and expected path of short rates on ECB monetary policy shocks, conditional on the lagged level of U.S. and Euro area debt outstanding (less central bank purchases) as a percent of GDP, expressed in z-scores and lagged one quarter. "Float/GDP" in the table refers to debt outstanding that is available to the public (e.g., net of central bank holdings). Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, plus 5-, 10-year German and French bond yields. Surprises are normalized to raise two year OIS by 10BP. Estimates are obtained using Huber biweights, robust standard errors appear in parentheses.

ship between inflation anchoring and spillovers, we condition the impact of ECB monetary policy shocks on a simple measure of anchored inflation expectations. Following Gürkaynak et al. (2006), we measure inflation expectations using the 9-year 1-year forward rate on nominal Treasuries less the 9-year 1-year forward rate on TIPS. We first test the impact of spillovers conditioning on an indicator equal to one if inflation expectations lie outside the historical interquartile range:

$$\Delta y_{US,t}^{(n)} = \alpha + \beta_1 \mathbb{1}[\pi_t^e \notin \{Q25, Q75\}] + \beta_2 MP_t^{ecb} + \beta_3 \mathbb{1}[\pi_t^e \notin \{Q25, Q75\}] \times MP_t^{ecb}$$
$$... + \gamma_1 PR_{t-1} + \gamma_2 (y_{US,t-1}^{n} - y_{EU,t-1}^{(n)}) + \epsilon_{it} \quad (11)$$

Where $y_{it}^{(n)}$ is either the yield on the n-year Treasury bond, the n-year term premium, or the expected path of short rates over an n-year horizon. We use the out-of-range indicator for two reasons. First, dummy interactions are straightforward to interpret. Second, and more importantly, the direction of inflation expectations' movement only signifies un-anchoring if 1.) expectations are moving away from the target and 2.) the magnitude of the deviation is outside some acceptable band.

Table 6 displays the results. Column 4 reflects the full specification (equation 11), suggesting that spillovers to the 10-year Treasury yield grow larger when inflation expectations are outside the interquartile range. Figure 9 plots the measure of inflation expectations, along with the 25^{th} and 75^{th} percentiles of those expectations. From this figure it becomes clear that inflation expectations deviated most from the interquartile range (IQR) from 2015 to the spring of 2021, when the rolling regressions suggest spillovers were largest. However, the literature on stock-bond correlations and inflation expectations tend to emphasize increases in inflation expectations as a driving factor eroding the convenience yield. We see in the figure that inflation expectations breached the 75^{th} percentile frequently before 2012, when spillovers were occasionally present but smaller in magnitude.

To test whether being above or below that band drives the effect, we split the estimate into above-IQR and below-IQR indicators. Table 6, column 5 suggests that periods with inflation expectations either above the 75^{th} percentile or below the 25^{th} are associated with enlarged spillovers. Although the point estimate associated with below-25^{th} percentile readings is larger, a Wald test cannot reject the null hypothesis that the impact of spillovers is equally

Table 6: Spillovers to the 10 year Treasury yield, conditional on inflation anchoring

	(1) Y_{10}	(2) Y_{10}	(3) Y_{10}	(4) Y_{10}	(5) Y_{10}	(6) TP_{10}	(7) SR_{10}
ECB	2.90***	1.09	1.31	1.01	1.05	-0.02	0.85*
	(0.82)	(1.06)	(1.04)	(1.08)	(1.09)	(0.73)	(0.51)
$\pi^e \notin \{Q25, Q75\}$=1		-0.68	-1.50*	-1.47*			
		(0.75)	(0.80)	(0.80)			
FFR_{t-1}			-0.49***	-0.54***	-0.54***	-0.33***	-0.14
			(0.19)	(0.19)	(0.19)	(0.13)	(0.09)
Y_{10}^{us} - Y_{10}^{eu}				-0.22	-0.66	-1.01**	0.30
				(0.46)	(0.66)	(0.44)	(0.31)
$\pi^e > Q75$=1					-2.07**	-1.35**	-0.55
					(0.99)	(0.66)	(0.46)
$\pi^e < Q25$=1					-0.63	0.43	-1.03*
					(1.29)	(0.86)	(0.60)
$\pi^e \notin \{Q25, Q75\}$=1 $\times$ ECB		5.01***	4.89***	5.22***			
		(1.67)	(1.64)	(1.66)			
$\pi^e > Q75$=1 $\times$ ECB					5.11***	3.32***	2.14**
					(1.85)	(1.23)	(0.86)
$\pi^e < Q25$=1 $\times$ ECB					5.25**	6.20***	0.54
					(2.65)	(1.77)	(1.23)
Constant	0.53	0.77	2.16***	2.41***	2.70***	2.21***	0.47
	(0.38)	(0.50)	(0.72)	(0.79)	(0.86)	(0.57)	(0.40)
Observations	265	265	265	259	259	259	259

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6 displays estimates regressing changes in 10-year U.S. zero coupon bond yields on ECB monetary policy shocks, conditional on a measure of unanchored inflation expectations. The inflation expectations are imputed according to Gürkaynak et al. (2006). A dummy variable is used in columns (2)-(4) to indicate a period of unanchored inflation expectations is equal to one when the imputed estimates lie outside the unconditional interquartile range. Columns (5)-(7) test whether being unanchored above or below the interquartile range have differential impact on the 10-year yield, term premium, and expected path of short rates respectively. Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, plus 5-, 10-year German and French bond yields. Surprises are normalized to raise two year OIS by 10BP. Estimates are obtained using Huber biweights, robust standard errors appear in parentheses.

large above and below the interquartile band.

$$\Delta y_{US,t}^{(n)} = \alpha + \beta_1 \mathbb{1}[\pi_t^e \geq Q75] + \beta_2 \mathbb{1}[\pi_t^e \leq Q25] + \beta_3 MP_t^{ecb} + \beta_4 \mathbb{1}[\pi_t^e \geq Q75] \times MP_t^{ecb}$$
$$... + \beta_5 \mathbb{1}[\pi_t^e \leq Q25] \times MP_t^{ecb} + \gamma_1 PR_{t-1} + \gamma_2 (y_{US,t-1}^{n} - y_{EU,t-1}^{(n)}) + \epsilon_{it} \quad (12)$$

Figure 9: Inflation expectations from 9y 1y forward rates

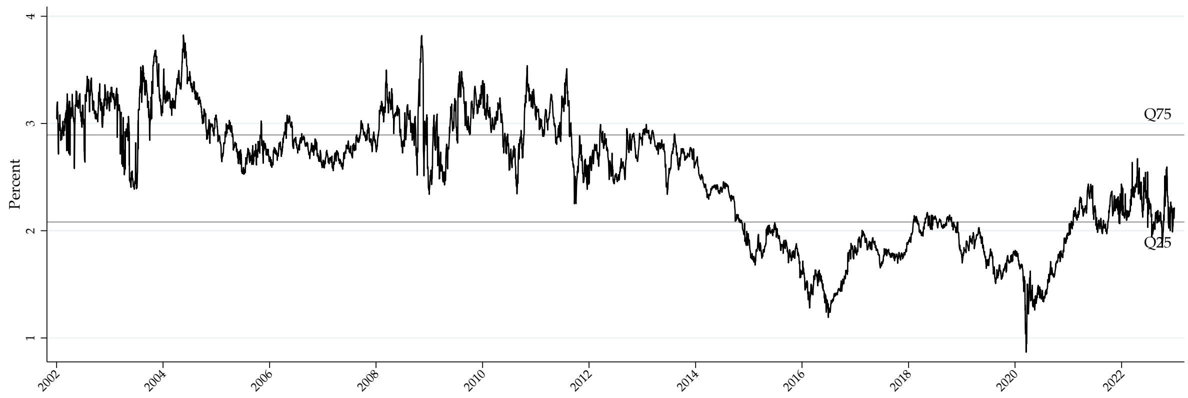


Figure 9 shows inflation expectations as proxied by the spread between nominal and TIPS 9-year 1-year foward rates.

A complementary strand of literature highlights the importance of balance sheet constraints among primary dealers and arbitrageurs in causing Treasuries to become "inconvenient" after the GFC (Klingler and Sundaresan (2023); Jermann (2020); Duffie (2023)). In particular, Du, Hébert, and Li (2023) and Klingler and Sundaresan (2023) draw a tight link between falling convenience yields and the breakdown in covered interest parity (CIP) observed post-crisis. We follow Du, Hébert, and Huber (2023) in measuring the shadow cost of intermediary constraints using violations of CIP, conditioning the impact of monetary policy shocks on the first principal component of the lagged CIP deviations (in absolute value) of the U.S. dollar against G10 currencies. Table 7 displays parameter estimates for the 10-year Treasury yield.

Keeping in mind that G10 CIP deviations are measured as absolute deviations from zero, these results suggest that spillovers from the ECB become larger when intermediary constraints assert themselves (i.e., when CIP deviations move away from zero). The parameter values suggest that a change in CIP deviations from average to one standard deviation away from historical average is associated with the spillover from a one standard deviation monetary policy shock increasing in magnitude from 3.9 basis points to 6.2 basis points. Consulting columns 5 - 6, the impact of balance sheet constraints is weighted heavily toward the term premium.

As a final check, we use to our advantage the observation from (Correa, Du, & Liao, 2020)

Table 7: Spillovers to the 10 year Treasury yield, conditional on intermediary constraints

	(1) Y_{10}	(2) Y_{10}	(3) Y_{10}	(4) Y_{10}	(5) TP_{10}	(6) SR_{10}
ECB	2.90***	3.69***	3.75***	3.93***	1.58***	1.84***
	(0.82)	(0.85)	(0.85)	(0.88)	(0.59)	(0.41)
10yr G10 CIP deviations		0.41	-0.01	0.19	0.23	-0.08
		(0.36)	(0.48)	(0.59)	(0.40)	(0.27)
FFR_{t-1}			-0.33	-0.32	-0.15	-0.12
			(0.24)	(0.26)	(0.17)	(0.12)
Y^{us}_{10} - Y^{eu}_{10}				-0.48	-0.75**	0.11
				(0.56)	(0.38)	(0.26)
ECB $\times$ 10yr G10 CIP deviations		2.16**	2.11**	2.31**	1.49**	0.40
		(0.91)	(0.91)	(0.95)	(0.64)	(0.44)
Constant	0.53	0.67*	1.25**	1.61**	1.53***	0.18
	(0.38)	(0.38)	(0.55)	(0.63)	(0.42)	(0.29)
Observations	265	256	256	250	250	250

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7 displays estimates regressing changes in 10-year Treasury yields on ECB monetary policy shocks, conditional the first principal component of G10 cross currency bases against the USD (expressed in z-scores and lagged by one calendar day) on ECB monetary policy shocks. Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, plus 5-, 10-year German and French bond yields. Surprises are normalized to raise two year OIS by 10BP. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

that quarter-ends are associated with spikes in intermediation spreads related to ”window-dressing”. To the extent that window dressing at the end of the quarter reduces engagement in balance sheet-intensive arbitrage, we should expect spillovers from ECB announcements near the end of the quarter to generate larger spillovers. In addition, because portfolio rebalancing arises uniquely from large scale asset purchases, we should expect limits to arbitrage to matter most for the impact of surprises reflected in longer maturities. The benefit of this exercise lay in delivering plausibly exogenous variation in Treasury inconvenience.

Table 8 displays the results conditioning the impact of spillovers on an indicator for the last 22 days of the quarter and, alternately, the day of the quarter on which the announcement was made. While columns 1 and 2 suggest that the full compound monetary policy surprise shows no variation in spillovers at the end of the quarter, columns 4 - 6 show that LSAP-type

Table 8: Spillovers to the U.S. yield curve at end-quarter

	(1) Y 10	(2) TP 10	(3) Y 10	(4) TP 10	(5) Y 10	(6) TP 10	(7) Y 10	(8) TP 10
ECB	3.168***	0.865						
	(1.063)	(0.716)						
FFR $t-1$	-0.366**	-0.237**	-0.313*	-0.221*	-0.309*	-0.221*	-0.320*	-0.220*
	(0.177)	(0.119)	(0.173)	(0.117)	(0.175)	(0.118)	(0.173)	(0.117)
End of Quarter	0.294	-0.0160	0.0281	-0.0294	0.0546	-0.0311		
	(0.796)	(0.536)	(0.787)	(0.534)	(0.796)	(0.540)		
EOQ ×MP	-0.460	0.130						
	(1.697)	(1.142)						
Target EU			0.321	0.137	-0.435	-0.150	0.304	0.126
			(0.365)	(0.248)	(0.513)	(0.348)	(0.366)	(0.248)
Path EU			1.434***	0.345	2.195***	0.555	1.435***	0.402
			(0.372)	(0.252)	(0.496)	(0.336)	(0.374)	(0.253)
LSAP EU			0.361	0.305	0.221	0.274	0.145	-0.0768
			(0.522)	(0.354)	(0.529)	(0.359)	(0.796)	(0.539)
EOQ ×LSAP			1.143	1.139**	1.304*	1.173**		
			(0.718)	(0.487)	(0.733)	(0.497)		
EOQ ×Target					0.979	0.451		
					(0.756)	(0.513)		
EOQ ×Path					-1.398*	-0.342		
					(0.781)	(0.530)		
Day in quarter							-0.0147	-0.0148
							(0.0209)	(0.0141)
LSAP EU × Day in quarter							0.0263	0.0301**
							(0.0214)	(0.0145)
Constant	1.189*	0.995**	1.084*	0.937**	1.140*	0.966**	1.573**	1.377**
	(0.611)	(0.411)	(0.599)	(0.406)	(0.603)	(0.409)	(0.787)	(0.532)
Observations	265	265	268	268	268	268	268	268

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8 displays estimates regressing changes in 10-year U.S. zero coupon bond yields and term premia on ECB monetary policy shocks, conditional on whether the policy surprise announcement occurred at the end of a fiscal quarter (within 22 days). Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, plus 5-, 10-year German and French bond yields. Surprises are normalized to raise two year OIS by 10BP. The decomposition of shocks into "Target", "Path", and "LSAP" reflect those obtained in Section 4.1. Estimates are obtained using Huber biweights, robust standard errors appear in parentheses.

surprises land harder at the end of the quarter, consistent with intermediation constraints. As added evidence, we observe in column 8 that the further along in the quarter is the announcement, the more an LSAP shock affects the term premium. Together, these exercises provide additional evidence linking exogenous shifts in the convenience yield to the time-varying strength of the portfolio balance channel.

Taken together, these exercises firmly support the notion that the convenience of Treasuries alters the impact of spillovers through the portfolio balance channel—developments that erode the specialness of Treasuries are associated with larger spillovers from the ECB. At the same time, the occasional presence of an effect through the expected path of short rates points to the existence of an international signaling or confidence channel between the ECB and the Fed. For example, it appears as though high upside unanchoring risk causes market participants to more forcefully update their expectations of Fed actions in response to ”news” generated by the ECB. The danger of unanchored inflation expectations is well known, and a credible Fed might be perceived as having a stronger incentive to act on the revelation of global news. We test the importance of the portfolio balance channel against other candidate explanations in the following section.

5 Alternative sources of time variation: News, Uncertainty and Risk Aversion

Rolling regressions in Figure 2 show that U.S. term premium shocks constitute the primary source of spillovers, and that their amplification during the low-for-long period contributed to the heightened overall sensitivity of the U.S. yield curve slope to ECB monetary policy. We therefore conclude that while an international signaling channel may exist, it is not the dominant factor accounting for the overall increase in spillovers to the Treasury yield curve. However, changes in the U.S. term premium wrought by monetary policy elsewhere could plausibly arise from sources other the changing nature of Treasuries. Given the provenance of monetary policy cycles in differing macroeconomic, financial and political conditions over time, we might surmise instead that changes in term premium spillovers result from changes in sentiment around global economic conditions.

To further refine our understanding of spillovers to the term premium and to validate the convenience channel we favor, we test two additional potential sources of time variation. Broadly speaking, the first set of competing explanations relate to other factors contributing to the portfolio balance channel. In particular, it may be the case that portfolio rebalancing from European sovereign bonds to Treasuries has varied due to changes in risk aversion or uncertainty. As risk-bearing capacity falls, arbitrageurs will find it more costly to integrate the markets for bonds. Similarly, in periods of elevated exchange rate volatility, the hedging cost of substituting across currencies may rise, decreasing the size of spillovers. The second potential source of time variation relates to the confidence channel, which reflects the degree to which international shocks influence interest rate risk. In this case, an expansion of the role that ECB monetary policy plays in generating uncertainty about the U.S. economy or of the conduct of U.S. monetary policy could raise the term premium. We address these two competing alternatives in turn.

We begin by running a horse race between our candidate explanation—growing inconvenience of Treasuries—against the influence of a changing risk environment. Given that preferred habitat investors become less willing to substitute to other maturities of the same broad asset when risk bearing capacity is low, willingness to substitute between international markets might also be suppressed under these conditions. To that end, we condition the impact of the monetary policy shock on four lagged uncertainty indices: the VIX, the MOVE index of option implied Treasury market volatility, the economic policy uncertainty index of Baker et al. (2016), and the monetary policy uncertainty index developed by (Husted, Rogers, & Sun, 2020).

Table 9, which displays spillovers to the 10-year yield and decomposition, suggests that the risk environment bears an inconsistent relationship with ECB spillovers to yields. Starting with measures that plausibly capture risk sentiment in columns 1 - 6, we see that neither the VIX or the MOVE index are associated with a change in the size of spillovers. Moreover, including the interaction between the ECB monetary policy shock and these measures of risk sentiment preserve the baseline result that term premium spillovers from unconventional monetary policy grow as Treasury convenience wanes.

Columns 7 - 12 condition on economic and monetary policy uncertainty, respectively. The signs on the interaction term ECB $\times$ EPU suggests that an increase in policy uncertainty is associated with smaller spillovers from ECB monetary policy, consistent with the idea that uncertainty hampers substitution. More importantly, however, the significant impact that EPU has on the size of spillovers does not diminish our baseline channel. Columns 10 and 11 suggest that the magnitude of term premium spillovers is unaffected by monetary policy

Table 9: ECB Spillovers Conditional on Risk and Risk Sentiment

	(1) Y_{10}	(2) TP_{10}	(3) SR_{10}	(4) Y_{10}	(5) TP_{10}	(6) SR_{10}	(7) Y_{10}	(8) TP_{10}	(9) SR_{10}	(10) Y_{10}	(11) TP_{10}	(12) SR_{10}	(13) Y_{10}	(14) TP_{10}	(15) SR_{10}
ECB	4.34***	1.96***	2.19***	4.10***	1.33*	2.30***	4.48***	2.47***	1.47***	3.83***	1.64***	2.14***	3.86***	1.68***	2.01***
	(1.05)	(0.71)	(0.48)	(1.01)	(0.68)	(0.45)	(0.94)	(0.63)	(0.43)	(0.91)	(0.61)	(0.40)	(0.92)	(0.63)	(0.42)
Swap spread$_{10}^{US}$	-0.25	0.01	0.21	-0.68	-0.66	0.00	-0.73	-1.11**	0.13	-0.24	-0.40	0.16	-0.20	-0.38	0.16
	(0.81)	(0.55)	(0.37)	(0.73)	(0.49)	(0.33)	(0.66)	(0.44)	(0.30)	(0.64)	(0.43)	(0.28)	(0.65)	(0.44)	(0.29)
ECB × Swap spread$_{10}^{US}$	1.94**	1.78***	-0.07	1.80*	1.55**	-0.28	2.44***	1.34**	0.46	1.74**	1.03**	0.13	1.75**	1.11**	0.26
	(0.93)	(0.63)	(0.42)	(0.95)	(0.64)	(0.42)	(0.85)	(0.56)	(0.39)	(0.73)	(0.49)	(0.32)	(0.73)	(0.50)	(0.33)
$MOVE_{t-1}$	0.13	0.92***	-0.11												
	(0.47)	(0.32)	(0.21)												
ECB × $MOVE_{t-1}$	-0.59	-0.35	-0.53												
	(0.75)	(0.51)	(0.34)												
FFR_{t-1}	-0.45	-0.13	-0.05	-0.48	-0.26	-0.14	-0.59*	-0.55**	-0.02	-0.47	-0.42*	-0.05	-0.45	-0.38*	-0.01
	(0.37)	(0.25)	(0.17)	(0.35)	(0.24)	(0.16)	(0.33)	(0.22)	(0.15)	(0.33)	(0.22)	(0.14)	(0.34)	(0.23)	(0.15)
VIX_{t-1}				-0.32	0.62**	-0.41**									
				(0.44)	(0.29)	(0.19)									
ECB × VIX_{t-1}				-0.10	0.14	-0.64**									
				(0.72)	(0.49)	(0.32)									
EPU_{t-1}							0.23	0.22	-0.02						
							(0.43)	(0.29)	(0.20)						
ECB × EPU_{t-1}							-1.45*	-1.33**	0.28						
							(0.83)	(0.56)	(0.38)						
MPU_{m_t-1}										-0.23	0.42	-0.46***			
										(0.38)	(0.26)	(0.17)			
ECB × MPU_{m_t-1}										-0.25	-0.90	0.99***			
										(0.84)	(0.56)	(0.37)			
Var(USD/EUR)													0.01	0.31	0.09
													(0.48)	(0.33)	(0.22)
ECB × Var(USD/EUR)													-0.23	0.03	-0.76***
													(0.64)	(0.43)	(0.29)
Constant	1.46**	0.98*	0.11	1.56**	1.22**	0.26	1.58**	1.46***	0.16	1.44**	1.40***	0.02	1.44**	1.23***	0.13
	(0.74)	(0.50)	(0.33)	(0.70)	(0.47)	(0.31)	(0.65)	(0.43)	(0.30)	(0.66)	(0.45)	(0.29)	(0.68)	(0.47)	(0.31)
Observations	242	242	242	234	234	234	236	236	236	259	259	259	259	259	259

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8 displays estimates regressing changes in 10-year U.S. zero coupon bond yields, term premia, and the expected path of short rates on ECB monetary policy shocks, conditioning on a lag of the VIX (col. 1 - 3), the MOVE index (col. 4 - 6), the Economic Policy Uncertainty Index of (Baker et al., 2016), the Monetary Policy Uncertainty Index of (Husted et al., 2020), and the 30-day rolling variance of the EUR/USD spot rate. Monetary policy surprises comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, 12-, and 24-month OIS rates, plus 5-, 10-year German and French bond yields. Surprises are normalized to raise two year OIS by 10BP. Estimates are obtained using Huber biweights, and robust standard errors appear in parentheses.

uncertainty, and that its inclusion preserves our baseline result.[13] Finally, under the hypothesis that an increase in spillovers could arise when exchange rate volatility is low, or else when hedging a position in dollars carries a comparatively low cost, columns 13 - 15 suggest that spillovers do not vary with 30-day spot exchange rate volatility between the dollar and the euro, and furthermore do not pull influence or significance from the baseline result.

It may be, instead, that foreign monetary policy alters the term premium by changing the volatility of short rates, or the premium associated with taking that risk on. To capture this element of the term premium, we use (Bundick, Herriford, & Smith, 2017)'s measure of

[13] While the parameter values pictured here utilize the narrowest definition of monetary policy news, our conclusions are robust to the inclusion of the broad index instead.

Figure 10: Time-varying ECB spillovers to the U.S. yield curve redux

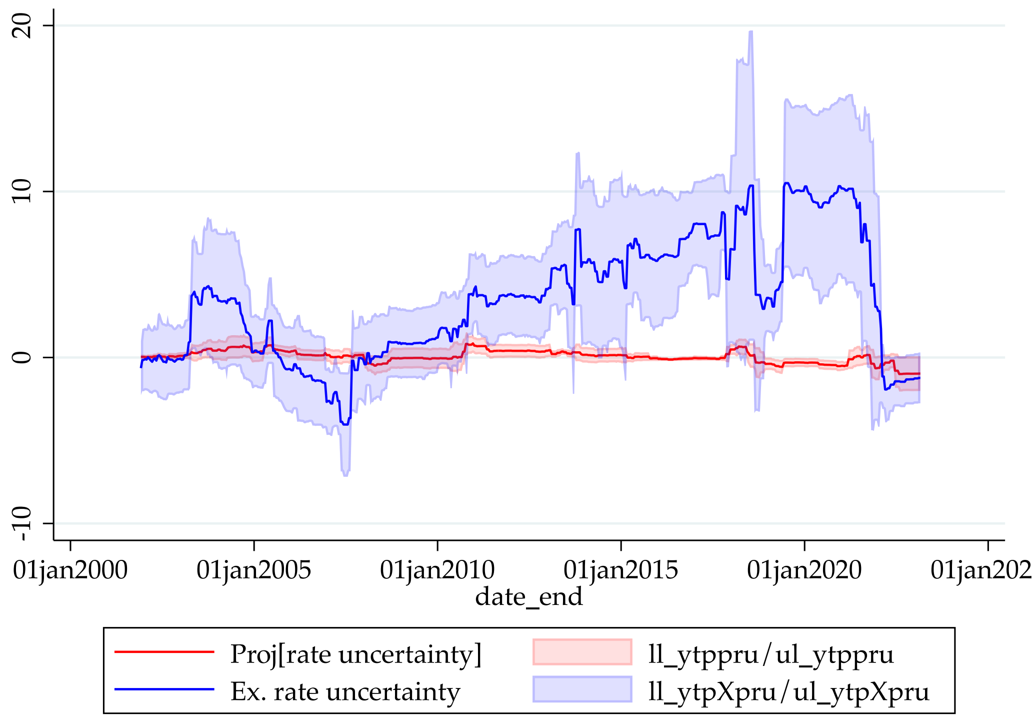


Figure 10 depicts estimates from a 700 business day (24 - 25 announcement) rolling regression of changes in the 10-year U.S. term premium on the z-scores of ECB monetary policy surprises. The yield is decomposed into the portion explained by short rate risk from (Bundick et al., 2017) and a residual. Monetary policy surprises comprise the first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, 5-, 10-year German and French bond yields. Shaded areas denote 90% robust confidence intervals.

policy rate uncertainty, extracted from option implied volatility of Eurodollar futures, and repeat the rolling regression from Figure 2b. Figure 10 depicts changes in the term premium decomposed into the portion that can be explained by movements in policy rate uncertainty (fitted rate uncertainty) and a residual orthogonalized from movements in short rate volatility. Although the element of the term premium that can be explained by short rate volatility is influenced by ECB monetary policy, the patterns we observed in our preferred specification are more consistent with the evolution of spillovers to the term premium excluding short rate volatility.

A final check repeats the rolling regressions from Section 2 with an added term meant to capture the impact an ECB announcement might have on perceptions of macroeconomic and financial risk. Following Leombroni et al. (2021), we decompose the monetary policy reaction into the future path of interest rates from default-free rate changes in these narrow intervals (MP_t^{ecb}), and the equity reaction that is orthogonal to changes in the stance of policy, ($\tilde{r}_t^{ecb}$). This term, derived from the intraday return on the STOXX50, is informative about risk premia and provides an identification of risk premium shocks emanating from monetary policy.[14]

$$\begin{aligned}
\Delta y_{US,t}^{(n)} &= \alpha + \beta_1 MP_t^{ecb} + \beta_2 \tilde{r}_t^{ecb} + \epsilon_{it} \\
\tilde{r}_t^{ecb} &= r_t - Proj[r_t | MP_t^{ecb}]
\end{aligned}$$

Figure 11 displays estimates from the rolling regression, along with the estimates from the baseline, in black. The baseline and the estimates controlling from for $\tilde{r}_t^{ecb}$ (in red) tend not to vary dramatically from one another. However, from roughly 2008 until roughly 2012, broad risk responses to ECB monetary policy do explain a larger portion of the term premium's response, taking into account statistical significance. While the effect of ECB monetary policy surprises on perceived US macroeconomic and financial risk is interesting in its own right, the patterns we observe here cannot rationalize our baseline findings because the timing is inconsistent with the emergence and growth of term premium spillovers post-Taper Tantrum.

Together, these results suggest that neither the uncertainty environment, nor the impact of ECB monetary policy on uncertainty, plays a substantial enough role in driving the size of spillovers from the ECB to U.S. Treasuries to displace changing convenience as the best explanation.

[14] Although we do not have access to intraday returns on the S&P 500 during ECB announcement intervals, we find that using daily S&P 500 returns in the same framework produces qualitatively similar results.

Figure 11: Time-varying ECB spillovers to the U.S. yield curve redux

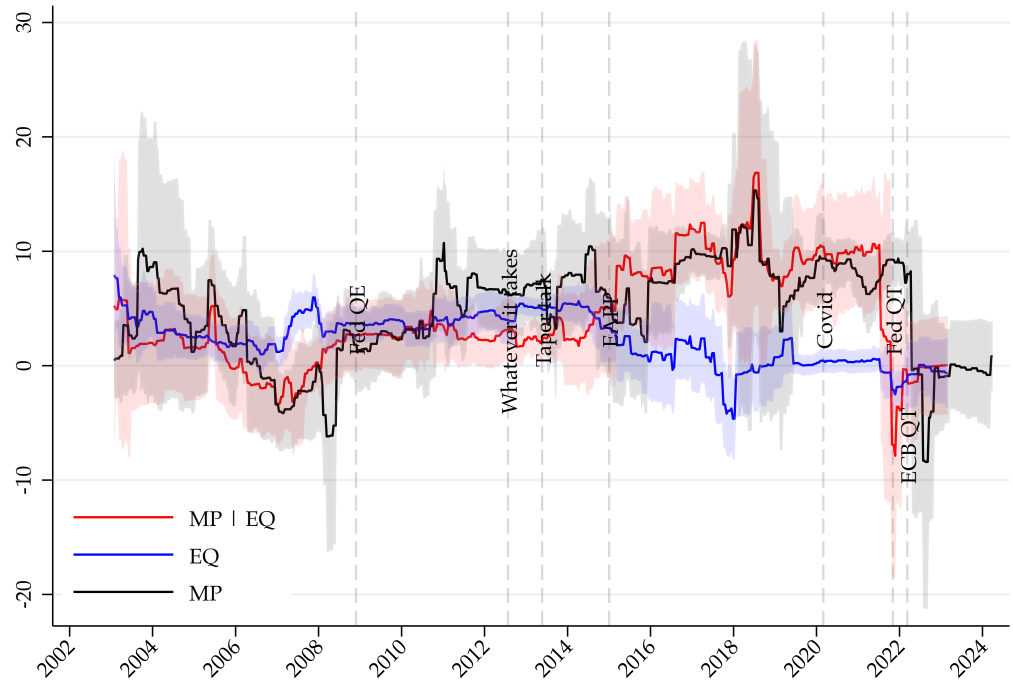


Figure 11 depicts estimates from a 700 business day (24 - 25 announcement) rolling regression of changes in 10-year U.S. zero coupon bond yields on the z-scores of ECB monetary policy surprises. Surprises comprise the first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, 5-, 10-year German and French bond yields. MP | EQ and EQ denote the parameter values obtained from decomposing the surprise into the future path of interest rates from default-free rate changes in these narrow intervals (MP_t^{ecb}), and the equity reaction that is orthogonal to changes in the stance of policy, ($\tilde{r}_t^{ecb}$). Shaded areas denote 90% robust confidence intervals.

6 Concluding Remarks and Directions for Future Research

In this paper, we show that international monetary spillovers to the U.S. yield curve are state-dependent and, since the Global Financial Crisis and adoption of unconventional monetary policy tools, governed by Treasury (in)convenience. Using high-frequency identification of ECB policy surprises, we document that spillovers intensified in the unconventional policy era and were strongest when U.S. normalization proceeded out of sync with other advanced economies. The convenience yield, and the characteristics that underlie it, are the linchpin of this state dependence: when convenience falls and Treasuries become less "special," their substitutability with other safe sovereigns rises, the portfolio-balance channel strengthens, and foreign shocks exert greater pressure on U.S. long rates. The transmission loads primarily on term premia and is more persistent at longer maturities, consistent with a portfolio balance channel of transmission.

We link this state dependence directly to movements in the convenience yield and to its determinants. In periods of elevated net Treasury supply (including when Federal Reserve absorption is limited), tighter intermediary balance-sheet constraints (proxied by CIP deviations), and less well-anchored inflation expectations, the convenience yield declines and spillovers strengthen; across these and other measures, each test echoes the same amplification pattern. Decomposing policy surprises shows that LSAP-type components account for the magnified term-premium response, while the signaling channel—encompassing target and forward-guidance elements and information effects—cannot explain the empirical patterns we observe. Competing narratives on risk sentiment, policy uncertainty, or exchange-rate volatility do not overturn the central role of the convenience yield in governing ECB spillovers to U.S. term premia. Taken together, the evidence implies that the effectiveness of domestic tightening will be attenuated in environments where foreign QE continues and the Treasury convenience yield is compressed.

Our theoretical contribution rationalizes these findings in a two-country preferred-habitat environment in which the convenience yield endogenously shapes the elasticity of demand for duration. Allowing demand slopes to vary with convenience produces state-contingent spillovers that are largest at intermediate and long maturities, replicating the term-premium-dominated transmission in the data. The combined empirical and model-based results underscore that insulation of U.S. long rates from foreign policy is not a structural constant; but rather, it is jointly determined by the scarcity value of Treasuries and policy asynchronicity across jurisdictions.

In future work, we plan to examine the degree to which similar patterns emerge in spillovers from the ECB to the U.K. conditional on Gilt convenience. This would help determine whether the portfolio balance mechanism of international spillovers is something unique to US Treasuries. Furthermore, within-domicile concerns of spillovers from the Treasuries to corporate borrowing costs–conditional on a waning convenience yield–could have large real and financial consequences.

From a more theoretical perspective, we have remained silent about a number of other concerns, which contain interest avenues for future research. First, our focus on the portfolio balance channel as driven through preferred habitat investors is targeted but perhaps incomplete in analyzing time-varying spillovers. Global arbitrageurs play a demonstrable role in international policy transmission, but we have not examined the degree to which their constraints and risk-preferences amplify or mitigate the spillovers. Similarly, as we noted in Section , the model is capable of addressing exchange rate risk concerns that may develop from a waning convenience yield. Finally, we have assumed an exogenous functional perturbation to the demand slopes, but there is a healthy theoretical literature discussing the underlying drivers of the convenience yield that future work could address. In other words, future research endogenizing the functional perturbation using existing causes in the literature would make a substantial contribution to our understanding. This is likely to be an easy extension of the model, requiring only functional chain rule terms.

Finally, there is the potential for secular changes in the convenience yield to reshape how we consider optimal policy making. Not only is the available mix of monetary policy tools expanding, the waning convenience yield suggests extant optimal policy making rules may be missing a crucial component. Our results suggest that US monetary policy and yield curve may not be as insulated from foreign shocks as we expect. In particular, that asynchronicity of strategy/tools and timing could hinder the effectiveness of domestic monetary policy. This suggests the possibility of a game-theoretic solution to optimal domestic policy.

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A Proofs

A.1 Proof of 3.1

We begin with the definition of $a_j(\tau)$, which satisfies the linear ODE:

$$a_j'(\tau) = -Ma_j(\tau) + e_j, \quad a_j(0) = 0.$$

The closed-form solution is:

$$a_j(M, \tau) = \left(I - e^{-M\tau}\right) M^{-1} e_j.$$

Differentiating this expression with respect to the matrix M, we obtain:

$$\partial_M a_j(M, \tau) = \left[\tau e^{-\tau M} - \left(I - e^{-M\tau}\right) M^{-1}\right] M^{-1} e_j.$$

This completes the proof of Proposition 3.1. The result characterizes how the sensitivity of yields to shocks—encoded in the vector $a_j(\tau)$—changes as the general equilibrium pricing environment M varies. This object plays a central role in tracing how monetary policy pass-through is modulated by deeper structural conditions.

A.2 Proof of Proposition 3.2

We begin by assuming $\alpha_H(\tau) \equiv \alpha_1(\tau),\ \alpha_F(\tau) \equiv \alpha_2(\tau) \in C^b(\mathbb{R})$, the Banach space of bounded functions equipped with the sup norm. The matrix $M \in \mathbb{M}_{5\times5}$ is implicitly defined as the solution to:

$$\Gamma^\dagger - \left(\theta_e e_3 - \alpha_e M^{-1}(e_1 - e_2)\right)\left(M^{-1}(e_1 - e_2)\right)^\dagger Q = M + \left[\sum_{j=1}^{2} \int_0^T \left(\theta_j(\tau) e_{3+j} - \alpha_j(\tau) a_j(\tau)\right) a_j(\tau)^\dagger \, d\tau\right] Q, \tag{13}$$

where e_k denotes the kth standard basis vector in $\mathbb{R}^5$, $\Gamma \in \mathbb{M}_{5\times5}$, $Q \equiv a\Sigma \otimes \Sigma \in \mathrm{Sym}_5$, and $\theta_e, \alpha_e \in \mathbb{R}$.

To analyze this implicit system, define the residual mapping:

$$\begin{aligned} X(M, \alpha_H, \alpha_F) &= M - \Gamma^\dagger + Y(M, \alpha_H, \alpha_F) Q + Z(M, \alpha_H, \alpha_F) Q, \\ Y(M, \alpha_H, \alpha_F) &= \sum_{j=1}^{2} \int_0^T \left(\theta_j(\tau) e_{3+j} - \alpha_j(\tau) a_j(\tau)\right) a_j(\tau)^\dagger \, d\tau, \\ Z(M, \alpha_H, \alpha_F) &= \left(\theta_e e_3 - \alpha_e M^{-1}(e_1 - e_2)\right)\left(M^{-1}(e_1 - e_2)\right)^\dagger. \end{aligned} \tag{14}$$

We are interested in the local solvability of this system for M as a function of (α_H, α_F). Define the solution set:

$$\Xi = \{(M, \alpha_H, \alpha_F) : X(M, \alpha_H, \alpha_F) = 0\}.$$

We invoke the Implicit Function Theorem on Banach spaces:

Theorem A.1 (IFT on Banach Spaces)**.** The set $\{(M, \alpha_H, \alpha_F) : M = \mu(\alpha_H, \alpha_F)\}$ is locally equivalent to Ξ if:

1. Ξ is non-empty;

2. $\partial_M X(M^0, \alpha_H^0, \alpha_F^0)$ is invertible for some $(M^0, \alpha_H^0, \alpha_F^0) \in \Xi$.

We assume the first condition is satisfied, consistent with the existence result in GRV. For the second, observe that

$$X : GL(5) \times C^b(\mathbb{R}) \times C^b(\mathbb{R}) \to \mathbb{M}_{5\times 5}$$

is continuously Fréchet differentiable in M, and $\partial_M X$ is a continuous linear mapping. By the Open Mapping Theorem (Banach's theorem), the inverse $(\partial_M X)^{-1}$ exists and is bounded on an open dense subset.

This completes the proof. The result ensures that the general equilibrium matrix M is a well-defined, locally differentiable function of the elasticity schedules $\alpha_H(\tau)$ and $\alpha_F(\tau)$, which play a structural role in shaping the yield curve through demand segmentation.

A.3 Proof of Proposition 3.3

We consider the residual mapping:

$$X(M, \alpha_H, \alpha_F) = M - \Gamma^\dagger + Y(M, \alpha_H, \alpha_F)Q + Z(M, \alpha_H, \alpha_F)Q,$$

with $Q = a\Sigma \otimes \Sigma$, and where:

$$Y(M, \alpha_H, \alpha_F) = -a\theta_0 \sum_{j=1}^{2} \left[e_{3+j} \left\{ (\theta_1 I + M)^{-1} \left(\frac{1}{\theta_1}(\theta_1 I + M)^{-1} e_j + \frac{1}{\theta_1^2} e_j \right) \right\}^\dagger \right],$$

$$Z(M, \alpha_H, \alpha_F) = a \sum_{j=1}^{2} \int_0^\infty \alpha_j(\tau) \left(I - e^{-M\tau} \right) M^{-1} e_j e_j^\dagger (M^{-1})^\dagger \left(I - e^{-M\tau} \right)^\dagger d\tau.$$

Define the solution set:

$$\Xi = \{(M, \alpha_H, \alpha_F) : X(M, \alpha_H, \alpha_F) = 0\}.$$

To show how the equilibrium matrix M responds to changes in α_H, α_F, we apply the Implicit Function Theorem on Banach spaces. This requires that $X : GL(5) \times C^b(\mathbb{R})^2 \to \mathbb{M}_{5\times 5}$ be continuously Fréchet differentiable, and that $\partial_M X$ be invertible at the solution.

Differentiating X with respect to M, we obtain:

$$\partial_M X = I + (\partial_M Y + \partial_M Z)\, Q.$$

Differentiating X with respect to α_k in the direction $\phi_k(\tau)$ yields:

$$(\partial_{\alpha_k} X)\, [\phi_k] = (\partial_{\alpha_k} Z)\, [\phi_k] Q,$$

where

$$(\partial_{\alpha_k} Z)\, [\phi_k] = \int_0^\infty \phi_k(\tau) \left(I - e^{-M\tau} \right) M^{-1} e_k e_k^\dagger (M^{-1})^\dagger \left(I - e^{-M\tau} \right)^\dagger d\tau.$$

Combining these expressions:

$$\sum_{k=1}^{2} (\partial_{\alpha_k} \mu)\, [\phi_k] = -\left\{ I + (\partial_M Y + \partial_M Z)\, Q \right\}^{-1} \left\{ \sum_k (\partial_{\alpha_k} Z)\, [\phi_k] \right\} Q.$$

This completes the proof. The result is not a standard matrix calculus derivation: it represents the Gâteaux derivative of an implicitly defined matrix-valued function, where the elasticity functions $\alpha_k(\tau)$ lie in an infinite-dimensional Banach space. Economically, this captures how micro-level variation in investor price sensitivity feeds back through the general equilibrium system to reshape M.

A.4 Proof of Theorem 3.1

Let $\Phi(\tau, q_t) = \sum_{k\in\{H,F\}} \partial_{\alpha_k} \log P_{jt}^{(\tau)}$. Since the bond price is affine in q_t, we write:

$$\log P_{jt}^{(\tau)} = -a_j(\tau)^\dagger q_t - c_j(\tau), \quad \Rightarrow \quad \Phi(\tau, q_t) = -\sum_k \left(\partial_M a_j(\tau) \cdot \partial_{\alpha_k}\mu\right)^\dagger q_t + \cdots .$$

Differentiating Φ using Itô's Lemma:

$$d\Phi = \Phi_q^\dagger \, dq_t = \Phi_q^\dagger \Gamma(\bar{q} - q_t)\, dt + \Phi_q^\dagger \Sigma \, db_t,$$

where $\Phi_q = -\sum_k \left(\partial_M a_j(\tau) \cdot \partial_{\alpha_k}\mu\right)$.

To compute the dynamic impact of a shock at time t, we use Malliavin calculus. The Malliavin derivative of Φ at time s is:

$$D_0\Phi(\tau, q_s) = Z_s^y \Sigma + \Phi_q^\dagger \Sigma,$$

where the variation process Z^y satisfies:

$$dZ_t^x = -\Gamma Z_t^x dt, \quad Z_t^x = e^{-t\Gamma}, \quad dZ_t^y = -\Phi_q^\dagger \Gamma Z_t^x dt, \quad Z_t^y = \Phi_q^\dagger e^{-t\Gamma}.$$

Thus, the impulse response of Φ to a shock h_t is:

$$h_t \cdot D_0\Phi(\tau, q_s) = h_t \cdot \left\{ \Phi_q^\dagger \left[I + e^{-(s-t)\Gamma} \right] \Sigma \right\}.$$

Finally, identifying $\Phi(\tau) = \partial_M a_j(\tau) \cdot \partial_{\alpha_H}\mu$, we conclude:

$$\partial^2_{\alpha_H, b} \log P_{js}^{(\tau)} = h_t \cdot \left\{ \Phi(\tau)^\dagger \left[I + e^{-(s-t)\Gamma} \right] \Sigma \right\}.$$

This completes the proof of Theorem 3.1. The result formalizes how a time-t elasticity shift affects the yield curve's future response to a one-time policy shock. The matrix $\Phi(\tau)$ carries the full general equilibrium adjustment, while the exponential dynamics encode how that effect decays or persists over time.

A.5 Proof of 3.2

We aim to solve for

$$\left(d_{\alpha_k} c_j\right)[\phi_k] = \left(\partial_M c_j\right)\left[\left(\partial_{\alpha_k}\mu\right)[\phi_k]\right] \times \left(\partial_{\alpha_k}\mu\right)[\phi_k] + \left(\partial_{\alpha_k} c_j\right)[\phi_k]$$

Begin with the vector-valued ODE for $c_j \in \mathbb{R}^5$

$$c_j' = a_j(\tau)^\top \left[\lambda_c + \Gamma\bar{q} + Q a_e 1_{j=F}\right] - \frac{1}{2} a_j(\tau)^\top Q a_j(\tau) \tag{15}$$

where $\bar{q} \in \mathbb{R}^5$, $1_{j=F}$ is the indicator function which equals one iff $j = F$, and

$$a_e = M^{-1}(e_1 - e_2) \tag{16}$$

$$\lambda_c = aQ\left[(\zeta_e - \alpha_e c_e) a_e + \sum_{j=H,F} \int_0^T (\zeta_j(\tau) - \alpha_j(\tau) c_j(\tau)) a_j(\tau) d\tau\right] \tag{17}$$

such that $\zeta_e, \alpha_e \in \mathbb{R}$, $\zeta_j(\tau) \in C^b(\mathbb{R})$, $\lambda_c \in \mathbb{R}^5$, and $c_e \in \mathbb{R}$ solves

$$-a_e^\top \Gamma \bar{q} - (\pi_F - \pi_H) + \frac{1}{2} a_e^\top Q a_e = a_e^\top \lambda_c$$

Proposition A.1. $c_j(\tau)$ is an nonautonomous function of the form

$$c_j\left(\tau, M, \alpha_{k\in\{H,F\}}\right) = -\frac{1}{2} f_j(\tau, M) + e_j^\top M^{-\top}\left[\tau I - M^{-1}\right]^\top Q\left[\chi_j\left(M, \alpha_{k\in\{H,F\}}\right) - \gamma_j\left(M, \alpha_j\right)\right]$$

Proof 1. Notice that, through 17, 15 is a Fredholm integro-differential equation:

$$\begin{aligned}
c_j' = & -\frac{1}{2} a_j(\tau)^\top Q a_j(\tau) \\
& + a_j(\tau)^\top Q\left[Q^{-1}\Gamma\bar{q} + a_e 1_{j=F} + a(\zeta_e - \alpha_e c_e) a_e\right] \\
& + a a_j(\tau)^\top Q\left[\sum_{k=H,F}\int_0^T \zeta_k(t) a_k(t) dt - \int_0^T \alpha_{-j}(t) c_{-j}(t) a_{-j}(t) dt\right] \\
& - a a_j(\tau)^\top Q\left[\int_0^T \alpha_j(t) c_j(t) a_j(t) dt\right]
\end{aligned}$$

Note that the kernel is already in separable form $-a a_j(\tau)^\top Q\left[\int_0^T \alpha_j(t) c_j(t) a_j(t) dt\right] = g(\tau)\int_0^T f(t) dt$. Thus we set $\gamma_j = a\int_0^T \alpha_j(t) c_j(t) a_j(t) dt \in \mathbb{R}^5$, define $\chi_j \equiv a\sum_{k=H,F}\int_0^T \zeta_k(t) a_k(t) dt - a\int_0^T \alpha_{-j}(t) c_{-j}(t) a_{-j}(t) dt + Q^{-1}\Gamma\bar{q} + a_e 1_{j=F} + a(\zeta_e - \alpha_e c_e) a_e$ and solve the following problem:

$$c_j' = -\frac{1}{2} a_j(\tau)^\top Q a_j(\tau) + a_j(\tau)^\top Q[\chi - \gamma]$$

Integrating both sides we get

$$c_j(\tau) = c_j(0) - \frac{1}{2}\int_0^\tau a_j(t)^\top Q a_j(t) dt + \int_0^\tau a_j(t)^\top dt Q[\chi - \gamma]$$

where $c_j(0) = 0$ by definition. Using **??** we have

$$\begin{aligned}
\int_0^\tau a_j(t) dt &= \int_0^\tau \left(I - e^{-tM}\right) dt M^{-1} e_j \\
&= \left[\tau I - M^{-1}\right] M^{-1} e_j
\end{aligned}$$

Not sure about this... for now, define $f_j(\tau) \equiv \int_0^\tau a_j(t)^\top Q a_j(t)\, dt$. Then

$$c_j(\tau) = -\frac{1}{2} f_j(\tau) + e_j^\top M^{-\top} \left[\tau I - M^{-1}\right]^\top Q \left[\chi - \gamma\right]$$

Plugging this into the definition of γ we get

$$\gamma = a \int_0^T \alpha_j(t) \left[-\frac{1}{2} f_j(t) + e_j^\top M^{-\top} \left[tI - M^{-1}\right]^\top Q \left[\chi - \gamma\right]\right] a_j(t)\, dt$$

Therefore the functional derivative with respect to M is

$$\begin{aligned}\left(\partial_M c_j\right)[Y] = &-\frac{1}{2}\left(\partial_M f_j(\tau, M)\right)[Y] - e_j^\top M^{-\top} Y^\top M^{-\top} \left[\tau I - M^{-1}\right]^\top Q \left[\chi\left(M, \alpha_j\right) - \gamma\left(M, \alpha_j\right)\right] \\ &+ e_j^\top M^{-\top} \left[M^{-1} Y M^{-1}\right]^\top Q \left[\chi\left(M, \alpha_j\right) - \gamma\left(M, \alpha_j\right)\right] \\ &+ e_j^\top M^{-\top} \left[\tau I - M^{-1}\right]^\top Q \left[\left(\partial_M \chi_j\right)[Y] - \left(\partial_M \gamma_j\right)[Y]\right]\end{aligned} \tag{18}$$

where

$$\left(\partial_M f_j(\tau, M)\right)[Y] = \int_0^\tau \left(\partial_M a_j(t)\right)[Y]^\top Q a_j(t) + a_j(t)^\top Q \left(\partial_M a_j(t)\right)[Y]\, dt \tag{19}$$

and

$$\begin{aligned}\left(\partial_M \chi_j\right)[Y] = &\, a \sum_{k=H,F} \int_0^T \zeta_k(t) \left(\partial_M a_k(t)\right)[Y]\, dt + \left(\partial_M c_{-j}(t)\right)[Y]\, 1_{j=F} + a\left(\zeta_e - \alpha_e c_e\right) a_e \\ &- a \int_0^T \alpha_{-j}(t) \left[\left(\partial_M c_{-j}(t)\right)[Y]\, a_{-j}(t) + c_{-j}(t) \left(\partial_M a_{-j}(t)\right)[Y]\right] dt \\ &+ \left(\partial_M a_e\right)[Y] \left\{1_{j=F} + a\left(\zeta_e - \alpha_e c_e\right)\right\} - a\alpha_e \left(\partial_M c_e\right)[Y]\, a_e\end{aligned} \tag{20}$$

and

$$\begin{aligned}\left(\partial_M \gamma_j\right)[Y] = &-\frac{a}{2} \int_0^T \alpha_j(t) \left(\partial_M f_j(t, M)\right)[Y]\, a_j(t)\, dt \\ &- a \int_0^T \alpha_j(t) \left[e_j^\top M^{-\top} Y^\top M^{-\top} \left[tI - M^{-1}\right]^\top Q \left[\chi - \gamma\right]\right] a_j(t)\, dt \\ &+ a \int_0^T \alpha_j(t) \left[e_j^\top M^{-\top} \left[M^{-1} Y M^{-1}\right]^\top Q \left[\chi - \gamma\right]\right] a_j(t)\, dt \\ &+ a \int_0^T \alpha_j(t) \left[e_j^\top M^{-\top} \left[tI - M^{-1}\right]^\top Q \left[\left(\partial_M \chi_j\right)[Y] - \left(\partial_M \gamma_j\right)[Y]\right]\right] a_j(t)\, dt \\ &+ a \int_0^T \alpha_j(t) \left[-\frac{1}{2} f_j(t, M) + e_j^\top M^{-\top} \left[tI - M^{-1}\right]^\top Q \left[\chi - \gamma\right]\right] \left(\partial_M a_j(t)\right)[Y]\, dt\end{aligned} \tag{21}$$

The partial functional derivative with respect to $\alpha_k(\tau)$ is

$$\left(\partial_{\alpha_k} c_j\right)[\phi_k] = e_j^\top M^{-\top} \left[\tau I - M^{-1}\right]^\top Q \left[\left(\partial_{\alpha_k} \chi_j\right)[\phi_k] - \left(\partial_{\alpha_k} \gamma_j\right)[\phi_k]\right] \tag{22}$$

where

$$\left(\partial_{\alpha_k}\chi_j\right)[\phi_k] = -a1_{j\neq k}\int_0^T \phi_k(t)\, c_k(t)\, a_k(t)\, dt - a\int_0^T \alpha_{-j}(t)\left(\partial_{\alpha_k}c_{-j}\right)[\phi_k]\, a_{-j}(t)\, dt \qquad (23)$$
$$- a\alpha_e\left(\partial_{\alpha_k}c_e\right)[\phi_k]\, a_e$$

and

$$\left(\partial_{\alpha_k}\gamma_j\right)[\phi_k] = a1_{j=k}\int_0^T \phi_k(t)\, c_k(t)\, a_k(t) + \alpha_k(t)\left(\partial_{\alpha_k}c_j\right)[\phi_k]\, a_k(t)\, dt \qquad (24)$$

There are still three quantities missing: $(\partial_M a_e)[Y]$, $(\partial_M c_e)[Y]$, and $(\partial_{\alpha_k}c_e)[\phi_k]$. The first is straightforward:

$$(\partial_M a_e)[Y] = -M^{-1}YM^{-1}(e_1 - e_2) \qquad (25)$$

The latter two will require another use of the Implicit Function Theorem on Banach spaces. c_e implicitly solves the following equation:

$$-a_e^\top\Gamma\bar{q} - (\pi_F - \pi_H) + \frac{1}{2}a_e^\top Q a_e = a_e \otimes \lambda_c$$

where λ_c is defined in 17. Define the level set $\Xi_2 = \{M, \alpha_H, \alpha_F : X_2(C_e, M, \alpha_H, \alpha_F) = 0\}$ where

$$X_2(C_e, M, \alpha_H, \alpha_F) = a_e \otimes \lambda_c(C_e, M, \alpha_H, \alpha_F) + a_e^\top\Gamma\bar{q} + \pi_F - \pi_H - \frac{1}{2}a_e^\top Q a_e$$

and it is understood that $a_e \equiv a_e(M) : GL(5) \to \mathbb{R}$ as defined in 16. The following corollary to 3.2 applies.

Corollary A.1. $\exists\mu_c(M, \alpha_H, \alpha_F) : GL(5)\times C^b(\mathbb{R})\times C^b(\mathbb{R}) \to \mathbb{R}\big| C_e = \mu_c(M, \alpha_H, \alpha_F)$ represents a graph identical to the level set Ξ_2 in a neighborhood $U_M \bigcup U_{ah}\bigcup U_{af}$ of $\{M^0, \alpha_H^0, \alpha_F^0\} \in \Xi_2$ such that $U_M \subset GL(5)$ and $U_{ah}, U_{af} \subset C^b(\mathbb{R})$.

Proof 2. Appeal to A.1 and the fact that $X_2 : \mathbb{R}\times GL(5)\times C^b(\mathbb{R})\times C^b(\mathbb{R}) \to \mathbb{R}$ is C^1. We show that $(\partial_{C_e}X_2)^{-1}$ exists directly:

$$(\partial_{C_e}X_2)[H] = -a\alpha_e H a_e^\top Q a_e \qquad (26)$$

as long as $a, \alpha_e \neq 0$ and Q is not skew-symmetric (satisfied by definition), then the only solution to $(\partial_{C_e}X_2)[H] = 0$ is the trivial one.

This allows us to use the following equations:

$$(\partial_M c_e)[Y] = (\partial_{C_e}X_2)^{-1}(\partial_M X_2)[Y]$$
$$(\partial_{\alpha_k}c_e)[\phi_k] = (\partial_{C_e}X_2)^{-1}(\partial_{\alpha_k}X_2)[\phi_k]$$

As $(\partial_{C_e}X_2)^{-1}$ is already given directly from 26, we need only derive $(\partial_M X_2)[Y]$ and $(\partial_{\alpha_k}X_2)[\phi_k]$. The latter is more straightforward, so we begin there.

$$\begin{aligned}(\partial_{\alpha_k}X_2)[\phi_k] &= a_e \otimes (\partial_{\alpha_k}\lambda_c)[\phi_k] \\ &= a_e \otimes \left\{Q\left(\partial_{\alpha_k}\chi_j\right)[\phi_k] - Q\left(\partial_{\alpha_k}\gamma_j\right)[\phi_k]\right\}\end{aligned}$$

using equations 23 and 24. For the former,

$$
\begin{aligned}
(\partial_M X_2)[Y] = (\partial_M a_e)[Y] \otimes [\lambda_c + \Gamma \bar{q}] + a_e \otimes (\partial_M \lambda_c)[Y] \\
- \frac{1}{2}\left[(\partial_M a_e)[Y]^\top Q a_e + a_e^\top Q (\partial_M a_e)[Y]\right]
\end{aligned}
$$

where

$$
\begin{aligned}
(\partial_M \lambda_c)[Y] = Q\left\{(\partial_M \chi_j)[Y] - (\partial_M \gamma_j)[Y]\right\} \\
- Q\left\{(\partial_M a_e)[Y]\left\{1_{j=F} + a(\zeta_e - \alpha_e c_e)\right\} + a\alpha_e (\partial_M c_e)[Y]\, a_e\right\}
\end{aligned}
$$

B Figures and Tables

Figure 1: ECB "News" shocks

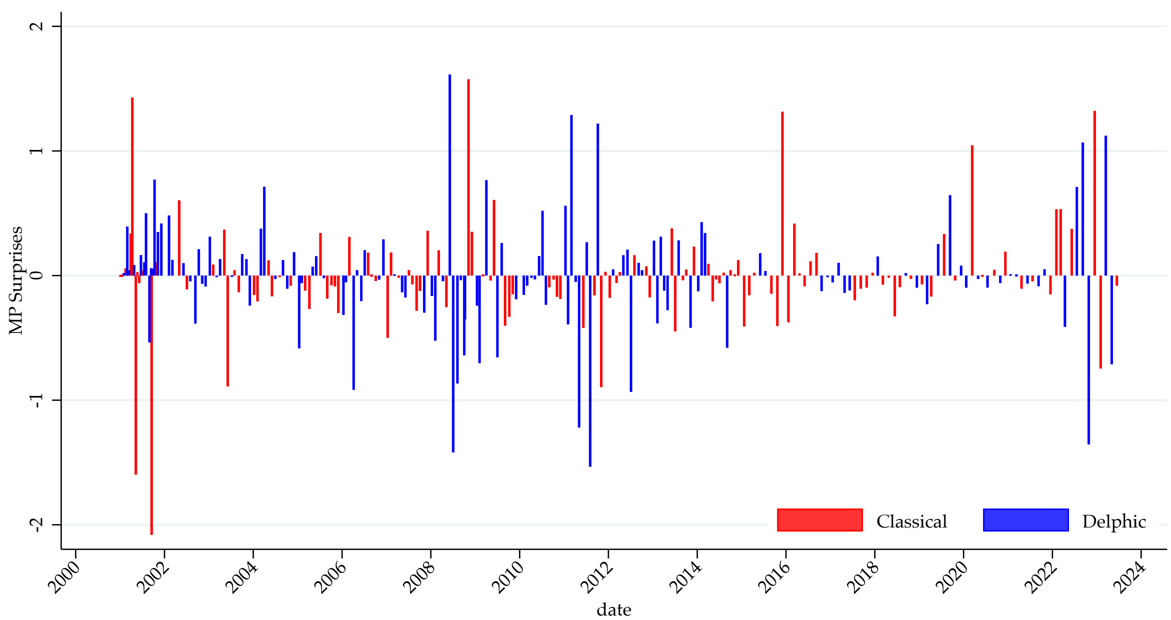

Figure 1 depicts z-scores of ECB monetary policy shocks. Shocks comprise the first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, 5-, 10-year German, Italian, French, and Spanish bond yields. Red shaded bars indicate negative stock-monetary policy comovement on the announcement day, while blue bars denote announcements marked by positive stock-bond comovement.

Table 1: Summary statistics

(a) Assets included in monetary policy surprises

	Mean	St. Dev.	Min	Max
OIS 1M	0.11	4.14	-35.00	19.50
OIS 3M	0.10	3.79	-30.00	16.15
OIS 6M	0.15	3.81	-21.50	16.60
OIS 1Y	0.20	4.44	-17.60	20.30
OIS 2Y	0.02	4.82	-22.80	18.70
DE5Y	0.03	4.55	-19.90	25.75
FR5Y	-0.08	4.73	-20.05	24.90
DE10Y	-0.01	3.28	-14.65	16.25
FR10Y	-0.07	3.71	-16.80	18.70

(b) Yields, yield decomposition, and conditioning variables

	Mean	St. Dev.	Min	Max
Δ 1yr Yield	-0.03	4.23	-59.54	40.47
Δ 5yr Yield	-0.05	5.91	-47.08	31.02
Δ 10yr Yield	-0.06	5.89	-51.89	33.09
Δ 1yr Term premium	-0.01	3.02	-88.74	86.55
Δ 5yr Term premium	-0.03	3.66	-42.84	39.81
Δ 10yr Term premium	-0.03	4.10	-33.43	34.50
Δ 1yr Expected path of Short Rates	-0.02	4.88	-84.64	93.30
Δ 5yr Expected path of Short Rates	-0.02	4.13	-47.45	50.09
Δ 10yr Expected path of Short Rates	-0.02	3.17	-31.17	34.02
US Swap spread: 1yr	0.32	0.23	-0.19	2.00
US Swap spread: 5yr	0.31	0.28	-0.12	1.28
US Swap spread: 10yr	0.26	0.32	-0.19	1.35
EA Swap spread: 1yr	0.33	0.24	-0.22	1.85
EA Swap spread: 5yr	0.39	0.20	0.06	1.12
EA Swap spread: 10yr	0.36	0.18	0.02	1.04
Treasuries outstanding ex. Fed (% GDP)	0.50	0.17	0.26	0.82

Table 1 displays summary statistics for our variables of interest. Table 1a displays summary statistics for the assets that we include in the compound monetary policy measure for the ECB, in basis points. Table 1b displays summary statistics for daily changes US Treasury yields, term premia, and the expected path of short rates in basis points, along with Treasury and Bund swap spreads ($OIS^n - Y^n$) in percent and Treasuries outstanding (excluding Fed holdings) as a percent of GDP.

Table 2: Breakpoints in the impact of ECB spillovers

Breaks	LL	UL
Mar 3, 2005	Feb 19, 2005	Mar 15, 2005
Mar 6, 2008	Mar 3, 2008	Mar 9, 2008
Feb 3, 2011	Jan 2, 2011	Mar 7, 2011
May 8, 2014	Jul 15, 1771	Mar 1, 2257
Jun 14, 2018	Jun 9, 2018	Jun 19, 2018

Table 2 displays estimated break points from a Bai Perron unknown breakpoint test, the mean of the ten year swap spread between break dates, the change in mean relative to the previous period, and 95% confidence intervals.

Table 3: Spillovers to the 1 year Treasury yield, conditional on convenience yields

	(1)	(2)	(3)	(4)	(5)	(6)
	Y_1	Y_1	Y_1	Y_1	Y_1	Y_1
ECB	1.90***	2.12***	2.05***	1.51***	2.40***	2.09***
	(0.39)	(0.43)	(0.44)	(0.44)	(0.44)	(0.41)
Y_1^{us} - Y_1^{eu}					-0.36	-0.17
					(0.46)	(0.45)
FFR_{t-1}			0.36***	-0.02	0.60	0.40
			(0.13)	(0.14)	(0.42)	(0.42)
MRO_{t-1}			-0.47**		-0.94*	-0.66
			(0.19)		(0.56)	(0.55)
Swap spread$_1^{US}$		-0.00	0.10	-0.19	-0.16	-0.10
		(0.16)	(0.21)	(0.30)	(0.31)	(0.31)
Swap spread$_1^{EU}$				0.40	0.20	0.19
				(0.27)	(0.28)	(0.28)
ECB $\times$ Swap spread$_1^{US}$		0.36	0.61*	0.51	0.63	
		(0.32)	(0.32)	(0.38)	(0.38)	
ECB $\times$ Swap spread$_1^{EU}$				-0.80***	0.38	
				(0.30)	(0.31)	
ECB $\times$ Y_1^{us} - Y_1^{eu}						-0.40
						(0.26)
Constant	0.13	0.12	0.14	0.19	0.63	0.47
	(0.18)	(0.18)	(0.32)	(0.32)	(0.52)	(0.52)
Observations	265	261	261	261	261	261

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4 displays estimates regressing changes in 1-year U.S. zero coupon bond yields, term premia, and expected path of short rates on the z-scores of ECB monetary policy shocks, conditional on the lagged level of Treasury and Bund convenience yields. Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, 5-, 10-year German, Italian, French, and Spanish bond yields. Shaded areas denote 90% robust confidence intervals. Convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap and are normalized to have zero mean and unit variance. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

Table 4: Spillovers to the 1 year Treasury yield, conditional on convenience yields

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Y_1	Y_1	Y_1	Y_1	Y_1	Y_1	TP_1	SR_1
ECB	1.90***	2.12***	2.05***	1.51***	2.40***	2.09***	0.58**	0.54
	(0.39)	(0.43)	(0.44)	(0.44)	(0.44)	(0.41)	(0.23)	(0.47)
Y_1^{us} - Y_1^{eu}					-0.36	-0.17		
					(0.46)	(0.45)		
FFR_{t-1}			0.36***	-0.02	0.60	0.40	-0.08	0.29*
			(0.13)	(0.14)	(0.42)	(0.42)	(0.08)	(0.15)
MRO_{t-1}			-0.47**		-0.94*	-0.66		
			(0.19)		(0.56)	(0.55)		
Swap spread$_1^{US}$		-0.00	0.10	-0.19	-0.16	-0.10	0.07	0.56*
		(0.16)	(0.21)	(0.30)	(0.31)	(0.31)	(0.16)	(0.32)
Swap spread$_1^{EU}$				0.40	0.20	0.19	0.00	0.15
				(0.27)	(0.28)	(0.28)	(0.15)	(0.29)
ECB × Swap spread$_1^{US}$		0.36	0.61*	0.51	0.63		0.15	-0.17
		(0.32)	(0.32)	(0.38)	(0.38)		(0.20)	(0.40)
ECB × Swap spread$_1^{EU}$				-0.80***	0.38		0.00	-0.74**
				(0.30)	(0.31)		(0.16)	(0.32)
ECB × Y_1^{us} - Y_1^{eu}						-0.40		
						(0.26)		
Constant	0.13	0.12	0.14	0.19	0.63	0.47	0.41**	-0.63*
	(0.18)	(0.18)	(0.32)	(0.32)	(0.52)	(0.52)	(0.17)	(0.34)
Observations	265	261	261	261	261	261	261	261

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4 displays estimates regressing changes in 1-year U.S. zero coupon bond yields, term premia, and expected path of short rates on the z-scores of ECB monetary policy shocks, conditional on the lagged level of Treasury and Bund convenience yields. Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, 5-, 10-year German, Italian, French, and Spanish bond yields. Shaded areas denote 90% robust confidence intervals. Convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap and are normalized to have zero mean and unit variance. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

Table 5: Spillovers to the 5 year Treasury yield, conditional on convenience yields

	(1) Y_5	(2) Y_5	(3) Y_5	(4) Y_5	(5) Y_5	(6) Y_5	(7) TP_5	(8) SR_5
ECB	3.38***	4.03***	4.03***	3.87***	4.09***	4.14***	1.99***	1.79***
	(0.79)	(0.87)	(0.88)	(0.99)	(0.99)	(0.84)	(0.61)	(0.55)
Y_5^{us} - Y_5^{eu}					-1.16	-1.32		
					(0.89)	(0.89)		
FFR_{t-1}			-0.02	-0.04	0.60	0.71	-0.34**	0.16
			(0.26)	(0.24)	(0.56)	(0.56)	(0.15)	(0.13)
MRO_{t-1}			0.13		-0.92	-1.06		
			(0.63)		(0.97)	(0.97)		
Swap spread$_5^{US}$		0.69**	0.86	0.74	0.93	1.06	-0.33	0.52**
		(0.33)	(0.84)	(0.47)	(0.86)	(0.85)	(0.29)	(0.26)
Swap spread$_5^{EU}$				0.61	0.51	0.52	0.29	0.24
				(0.38)	(0.40)	(0.40)	(0.24)	(0.21)
ECB × Swap spread$_5^{US}$		1.03*	1.02*	0.88	0.78		0.50	0.19
		(0.61)	(0.62)	(0.62)	(0.62)		(0.38)	(0.34)
ECB × Swap spread$_5^{EU}$				-0.31	-0.29		0.55	-0.21
				(0.68)	(0.68)		(0.42)	(0.37)
ECB × Y_5^{us} - Y_5^{eu}						-0.25		
						(0.76)		
Constant	0.43	0.42	0.25	0.44	1.68	1.82	1.08***	-0.21
	(0.36)	(0.37)	(0.95)	(0.55)	(1.39)	(1.39)	(0.34)	(0.31)
Observations	265	261	261	261	261	261	261	261

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5 displays estimates regressing changes in 5-year U.S. zero coupon bond yields, term premia, and expected path of short rates on the z-scores of ECB monetary policy shocks, conditional on the lagged level of Treasury and Bund convenience yields. Shocks comprise first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, 5-, 10-year German, Italian, French, and Spanish bond yields. Shaded areas denote 90% robust confidence intervals. Convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap and are normalized to have zero mean and unit variance. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

Table 6: Spillovers to the 1 year Treasury yield decomposition, conditional on convenience yields

	(1) Y_1	(2) Y_1	(3) TP_1	(4) TP_1	(5) SR_1	(6) SR_1
Target EU	-0.00	-0.01	0.35***	0.31***	-0.58**	-0.49**
	(0.20)	(0.20)	(0.11)	(0.11)	(0.22)	(0.22)
Path EU	0.97***	0.92***	0.01	0.03	0.93***	0.92***
	(0.20)	(0.20)	(0.11)	(0.11)	(0.22)	(0.22)
LSAP EU	0.16	0.15	0.44***	0.42***	-0.07	-0.10
	(0.21)	(0.20)	(0.12)	(0.12)	(0.23)	(0.23)
Y_1^{us} - Y_1^{eu}		-0.55		-0.16		0.19
		(0.45)		(0.26)		(0.50)
FFR_{t-1}		0.66		0.03		0.05
		(0.42)		(0.24)		(0.47)
MRO_{t-1}		-1.11**		-0.12		0.28
		(0.55)		(0.31)		(0.61)
Swap spread$_1^{US}$	-0.25	-0.70**	0.11	0.09	0.16	0.41
	(0.17)	(0.31)	(0.09)	(0.18)	(0.19)	(0.34)
Swap spread$_1^{EU}$		0.23		-0.13		0.17
		(0.27)		(0.16)		(0.30)
Target EU × Swap spread$_1^{US}$	0.51***	0.47***	0.27***	0.23***	0.16	0.22
	(0.14)	(0.14)	(0.08)	(0.08)	(0.16)	(0.16)
Path EU × Swap spread$_1^{US}$	-0.32**	-0.33**	-0.13*	-0.14*	-0.29*	-0.32**
	(0.14)	(0.14)	(0.08)	(0.08)	(0.16)	(0.16)
LSAP EU × Swap spread$_1^{US}$	-0.09	-0.01	-0.05	-0.14	-0.40	-0.31
	(0.32)	(0.32)	(0.18)	(0.18)	(0.36)	(0.36)
Constant	0.15	0.98*	0.31***	0.55*	-0.23	-0.88
	(0.18)	(0.51)	(0.10)	(0.29)	(0.20)	(0.57)
Observations	264	264	264	264	264	264

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6 displays estimates regressing changes in the 1-year U.S. term premia, and expected path of short rates on the z-scores of ECB monetary policy shocks, conditional on the lagged level of Treasury and Bund convenience yields (expressed as z-scores). Shocks comprises the first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, along with 5- and 10-year Gilt yields. Convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

Table 7: Spillovers to the 5 year Treasury yield decomposition, conditional on convenience yields

	(1) Y_5	(2) Y_5	(3) TP_5	(4) TP_5	(5) SR_5	(6) SR_5
Target EU	1.11^{**}	1.14^{**}	0.22	0.28	0.33	0.37
	(0.44)	(0.45)	(0.27)	(0.28)	(0.25)	(0.25)
Path EU	1.64^{***}	1.72^{***}	0.37	0.36	1.09^{***}	1.10^{***}
	(0.36)	(0.37)	(0.23)	(0.23)	(0.21)	(0.21)
LSAP EU	1.34^{**}	1.21^{**}	1.10^{***}	1.07^{***}	0.24	0.17
	(0.54)	(0.55)	(0.34)	(0.34)	(0.31)	(0.31)
Y_5^{us} - Y_5^{eu}		-0.76		0.05		-0.64
		(0.88)		(0.55)		(0.49)
FFR_{t-1}		0.37		-0.33		0.48
		(0.55)		(0.34)		(0.31)
MRO_{t-1}		-0.41		0.27		-0.69
		(0.95)		(0.60)		(0.54)
Swap spread$_5^{US}$	0.69^{**}	1.09	0.23	0.11	0.04	0.04
	(0.33)	(0.85)	(0.20)	(0.53)	(0.19)	(0.48)
Swap spread$_5^{EU}$		0.30		0.15		0.08
		(0.39)		(0.24)		(0.22)
Target EU × Swap spread$_5^{US}$	0.51^{*}	0.44	-0.05	-0.01	0.39^{**}	0.38^{**}
	(0.28)	(0.29)	(0.18)	(0.18)	(0.16)	(0.16)
Path EU × Swap spread$_5^{US}$	-0.45^{*}	-0.45^{*}	0.05	0.01	-0.24^{*}	-0.20
	(0.26)	(0.26)	(0.16)	(0.16)	(0.15)	(0.15)
LSAP EU × Swap spread$_5^{US}$	-0.77	-0.67	-0.16	-0.19	-0.43	-0.37
	(0.60)	(0.61)	(0.38)	(0.38)	(0.34)	(0.35)
Constant	0.38	0.94	0.52^{**}	0.64	0.07	0.83
	(0.36)	(1.37)	(0.23)	(0.86)	(0.21)	(0.77)
Observations	264	264	264	264	264	264

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7 displays estimates regressing changes in the 5-year U.S. term premia, and expected path of short rates on the z-scores of ECB monetary policy shocks, conditional on the lagged level of Treasury and Bund convenience yields (expressed as z-scores). Shocks comprises the first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, along with 5- and 10-year Gilt yields. Convenience yields are proxied by the spread between the sovereign bond yield and the maturity matched overnight index swap. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

Table 8: Spillovers to the 10 year Treasury yield decomposition, conditional on net bond supply

	Term Premium				**Expected Path of Short Rates**			
	(1) TP_{10}	(2) TP_{10}	(3) TP_{10}	(4) TP_{10}	(5) SR_{10}	(6) SR_{10}	(7) SR_{10}	(8) SR_{10}
ECB	1.00^{*}	0.96^{*}	1.24^{**}	1.28^{**}	1.53^{***}	1.53^{***}	1.58^{***}	2.26^{***}
	(0.57)	(0.56)	(0.58)	(0.59)	(0.38)	(0.39)	(0.40)	(0.37)
Float/GDP (US)	-0.17	-0.81^{**}	-0.59	-0.17	0.05	-0.03	-0.35	-0.47
	(0.25)	(0.31)	(0.55)	(0.66)	(0.17)	(0.22)	(0.38)	(0.42)
FFR_{t-1}		-0.48^{***}	-0.44^{**}	-0.24		-0.05	-0.17	0.70^{***}
		(0.15)	(0.19)	(0.38)		(0.10)	(0.13)	(0.24)
Y^{us}_{10} - Y^{eu}_{10}			-0.19	-0.21			0.29	-1.28^{**}
			(0.53)	(0.79)			(0.37)	(0.50)
Float/GDP (EU)				0.19				-0.08
				(0.37)				(0.23)
ECB $\times$ Float/GDP (US)	0.30	0.24	0.57	0.45	0.77^{**}	0.74^{*}	0.75^{*}	-0.12
	(0.56)	(0.54)	(0.57)	(0.59)	(0.38)	(0.38)	(0.40)	(0.37)
MRO_{t-1}				0.17				-1.58^{***}
				(0.60)				(0.38)
Constant	0.46^{*}	1.35^{***}	1.42^{***}	0.93	0.15	0.25	0.16	2.41^{***}
	(0.26)	(0.37)	(0.44)	(1.10)	(0.17)	(0.25)	(0.30)	(0.70)
Observations	265	265	259	229	265	265	259	229

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8 displays estimates regressing changes in 10-year U.S. zero coupon term premia, and expected path of short rates on the z-scores of ECB monetary policy shocks, conditional on the lagged level of U.S. and Euro area debt outstanding (less central bank purchases) as a percent of GDP, expressed in z-scores and lagged one quarter. "Float/GDP" in the table refers to debt outstanding that is available to the public (e.g., net of central bank holdings). Shocks comprises the first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, along with 5- and 10-year yields. Estimates are obtained using Huber biweights, robust standard errors appear in parentheses.

Table 9: Spillovers to the 10 year Treasury yield decomposition, conditional on intermediary constraints

	Term Premium			Expected Path of Short Rates		
	(1)	(2)	(3)	(4)	(5)	(6)
	TP_{10}	TP_{10}	TP_{10}	SR_{10}	SR_{10}	SR_{10}
ECB	1.35**	1.30**	1.58***	1.75***	1.77***	1.84***
	(0.59)	(0.58)	(0.59)	(0.39)	(0.39)	(0.41)
10yr G10 CIP deviations	0.05	-0.32	0.23	0.11	0.04	-0.08
	(0.25)	(0.33)	(0.40)	(0.17)	(0.22)	(0.27)
FFR_{t-1}		-0.29*	-0.15		-0.06	-0.12
		(0.16)	(0.17)		(0.11)	(0.12)
Y_{10}^{us} - Y_{10}^{eu}			-0.75**			0.11
			(0.38)			(0.26)
ECB × 10yr G10 CIP deviations	1.31**	1.22*	1.49**	0.37	0.35	0.40
	(0.63)	(0.63)	(0.64)	(0.42)	(0.42)	(0.44)
Constant	0.62**	1.11***	1.53***	0.12	0.22	0.18
	(0.26)	(0.38)	(0.42)	(0.17)	(0.25)	(0.29)
Observations	256	256	250	256	256	250

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 9 displays estimates regressing changes in the 10-year Treasury term premium and expected path pf short rates on ECB monetary policy shocks, conditional the first principal component of G10 cross currency bases against the USD, expressed in z-scores and lagged by one calendar day. Shocks comprises the first principal component of intradaily changes in the following: 1-, 3-, 6-, and 24-month OIS rates, along with 5- and 10-year sovereign bond yields. Estimates are obtained using Huber biweights and robust standard errors appear in parentheses.

Table 10: Spillovers to the 10 year Treasury yield, conditional on inflation anchoring

	Term Premium				**Expected Path of Short Rates**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	TP_{10}	TP_{10}	TP_{10}	TP_{10}	SR_{10}	SR_{10}	SR_{10}	SR_{10}
ECB	-0.32	-0.21	-0.09	-0.02	0.89*	0.92*	0.89*	0.85*
	(0.71)	(0.70)	(0.72)	(0.73)	(0.48)	(0.48)	(0.50)	(0.51)
$\pi^e \notin \{Q25, Q75\}$=1	-0.22	-0.74	-0.71		-0.59*	-0.76**	-0.79**	
	(0.50)	(0.54)	(0.53)		(0.34)	(0.37)	(0.37)	
FFR_{t-1}		-0.30**	-0.33***	-0.33***		-0.12	-0.14	-0.14
		(0.13)	(0.12)	(0.13)		(0.09)	(0.09)	(0.09)
Y_{10}^{us} - Y_{10}^{eu}			-0.51*	-1.01**			0.15	0.30
			(0.31)	(0.44)			(0.21)	(0.31)
$\pi^e > Q75$=1				-1.35**				-0.55
				(0.66)				(0.46)
$\pi^e < Q25$=1				0.43				-1.03*
				(0.86)				(0.60)
$\pi^e \notin \{Q25, Q75\}$=1 × ECB	3.83***	3.77***	3.44***		1.39*	1.40*	1.48*	
	(1.12)	(1.11)	(1.11)		(0.76)	(0.76)	(0.77)	
$\pi^e > Q75$=1 × ECB				3.32***				2.14**
				(1.23)				(0.86)
$\pi^e < Q25$=1 × ECB				6.20***				0.54
				(1.77)				(1.23)
Constant	0.56	1.43***	1.86***	2.21***	0.40*	0.70**	0.58	0.47
	(0.34)	(0.49)	(0.53)	(0.57)	(0.23)	(0.33)	(0.37)	(0.40)
Observations	265	265	259	259	265	265	259	259

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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Table 11: ECB Spillovers Conditional on Risk Sentiment

	(1) Y_5	(2) TP_5	(3) SR_5	(4) Y_5	(5) TP_5	(6) SR_5	(7) Y_5	(8) TP_5	(9) SR_5	(10) Y_5	(11) TP_5	(12) SR_5
ECB	4.85***	1.21**	2.39***	4.49***	1.81***	1.94***	3.91***	1.96***	1.74***	3.47***	1.78***	2.02***
	(0.91)	(0.58)	(0.50)	(0.99)	(0.63)	(0.54)	(0.88)	(0.54)	(0.47)	(0.82)	(0.49)	(0.44)
VIX_{t-1}	-0.77**	0.30	-0.42**									
	(0.37)	(0.24)	(0.20)									
ECB × VIX_{t-1}	-0.36	0.22	-0.79**									
	(0.67)	(0.43)	(0.37)									
$MOVE_{t-1}$				-0.27	0.37	-0.02						
				(0.36)	(0.23)	(0.19)						
ECB × $MOVE_{t-1}$				-0.37	-0.65	0.97**						
				(0.66)	(0.42)	(0.45)						
EPU_{t-1}							0.20	0.02	-0.03			
							(0.39)	(0.24)	(0.21)			
ECB × EPU_{t-1}							-0.23	-1.15**	0.53			
							(0.78)	(0.48)	(0.42)			
MPU_{t-1}										-0.39	-0.08	-0.04
										(0.42)	(0.25)	(0.22)
ECB × MPU_{t-1}										-0.31	-1.84***	1.63***
										(0.82)	(0.49)	(0.44)
Constant	0.46	0.66***	0.08	0.37	0.64***	0.08	0.45	0.57**	0.18	0.24	0.53**	0.08
	(0.36)	(0.23)	(0.20)	(0.36)	(0.23)	(0.19)	(0.40)	(0.25)	(0.21)	(0.39)	(0.23)	(0.21)
Observations	240	240	240	248	248	247	242	242	242	265	265	265

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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