Granular Treasury Demand with Arbitrageurs

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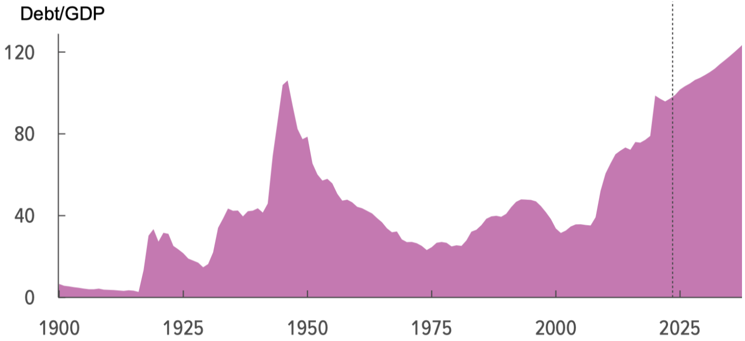
The Rise of the U.S. Debt Burden



- Since the rise in debt levels, the U.S. Treasury market experienced several episodes of disruptions (e.g., taper tantrum, March 2020 Covid-19).
    - Raises concerns about investors' capacity to absorb U.S. debt.

This Paper

- Who is willing to absorb government debt and how does that demand vary with prices and macroeconomy? What is the role of arbitrageurs and the Fed?

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- We quantify an equilibrium model of the Treasury market with a novel granular dataset.
- A methodological advance to combine insights of two influential literature:
  - Demand-based asset pricing (Koijen and Yogo 2019):
    Contribution: Allowing for no-arbitrage conditions.
  - Preferred habitat view (Vayanos and Vila 2021):
    Contribution: Introducing cross elasticities and quantification with granular data.

Step #1: Estimate empirically tractable demand curves

- Collect a novel dataset on most U.S. Treasury holdings at the maturity level:
  1. Granular-demand investors (e.g., insurance companies, MMFs, banks)
  2. The Federal Reserve

- Use the following ingredients to estimate demand curves:
  1. Own and cross price elasticity (using an IV methodology)
  2. Bond characteristics (e.g., coupon rate, maturity)
  3. Macroeconomic variables (e.g., inflation, GDP gap, credit spread)

- Why demand estimation? To capture rich heterogeneity of institutional features.
  1. Banks: liquidity regulation, capital regulation, etc.
  2. Insurance companies: long-duration liabilities and capital regulation.
  3. Fed: policy goals.

Step #2: Embed estimates in Treasury equilibrium model

- An equilibrium model built on Vayanos and Vila (2021), with three key deviations:
  1. Cross substitution among maturities.
  2. Monetary policy depending on macro variables rather than exogenously determined.
  3. Arbitrageurs still maximize profit but have "outside assets".

- Model entirely estimated using data, including arbitrageurs' Treasury holdings.
  - Who are arbitrageurs? – Primary dealers and hedge funds (Hanson and Stein 2015; Du, Hebert, Li 2023).

- Model estimation reveals:
  1. Treasury market is elastic because of low estimated arbitrageur risk aversion.
  2. Positive term premium response to monetary policy hike, due to cross elasticity.
  3. Power of QE policy hinges on perceived persistence of Fed purchases.

Contribution to the Literature

1. Demand-based asset pricing (e.g., Koijen and Yogo 2019, Bretscher et al. 2020, Chaudhary et al. 2022, Fang et al. 2022, Jansen 2023, Eren et al. 2023)
2. Preferred habitat view term structure of interest rates (e.g., Culbertson 1957, Modigliani and Sutch 1966, Guidbaud et al. 2013, Greenwood and Vayanos 2014, Vayanos and Vila 2021, Droste et al. 2021, Kekre et al. 2024)
3. Specialty of U.S. debt (e.g., Krishnamurthy and Vissing-Jorgensen 2012, Nagel 2016, Drechsler et al. 2018, Jiang et al. 2019, Diamond and Van Tassel 2021, Krishnamurthy and Li 2023, Acharya and Laarits 2023, Brunnermeier et al. 2024)
4. Intermediary asset pricing (e.g., He and Krishnamurthy 2013, Adrian et al. 2014, He et al. 2017, Du et al. 2018, Haddad and Muir 2021, Fang and Liu 2021, Kargar 2021, Du et al. 2023, d'Avernas et al. 2023)

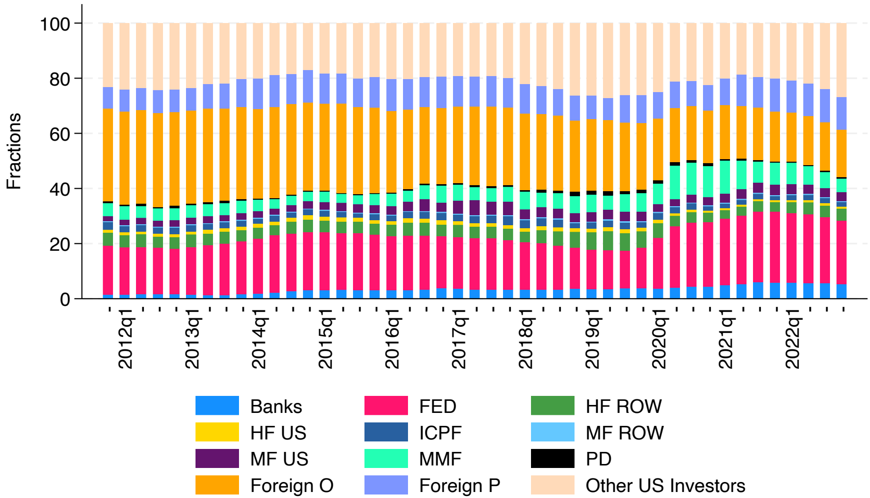
Key contribution: combining granular demand analysis with equilibrium model quantification.

Data Sources

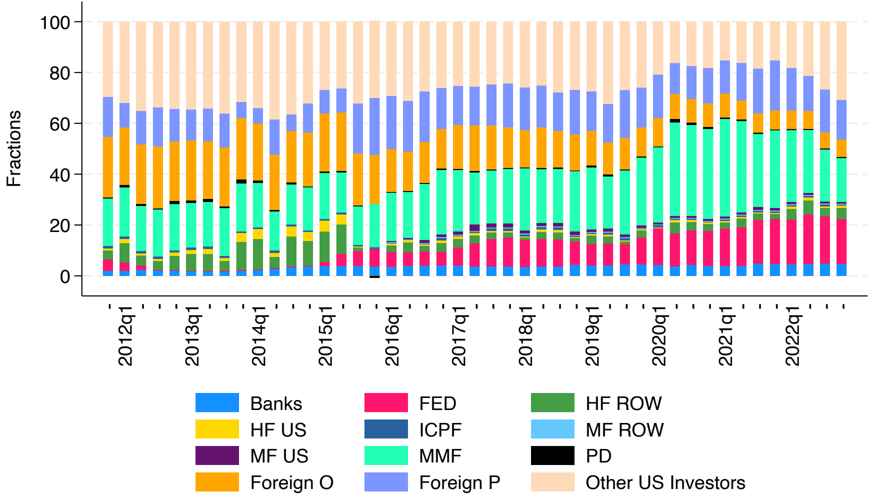
Investor Type	Data Source	Frequency	Period	Detail
Banks	CALL Reports	Quarterly	1976Q1-2022Q4	Maturity bucket
Fed	Federal Reserve	Weekly	2003W1-2022W52	Security
Primary Dealers	Federal Reserve	Weekly	1998W5-2022W52	Maturity bucket
Hedge Funds	Form PF SEC	Quarterly	2011Q4-2022Q4	Aggregate
Insurers and Pension Funds	eMAXX	Quarterly	2010Q1-2022Q4	Security
Money Market Funds	IMoneyNet	Monthly	2011M8-2022M12	Security
Mutual Funds	Morningstar	Monthly/Quarterly	2000M1-2022M12	Security
ETFs	ETF Global	Daily/Monthly	2012M1-2022M12	Security
Foreign Official and Private	Public TIC	Quarterly	2011Q4-2022Q4	T-bill/non T-bill

- We group data into three maturity buckets: $T \leq 1Y$, $1Y < T \leq 5Y$, and $T > 5Y$.

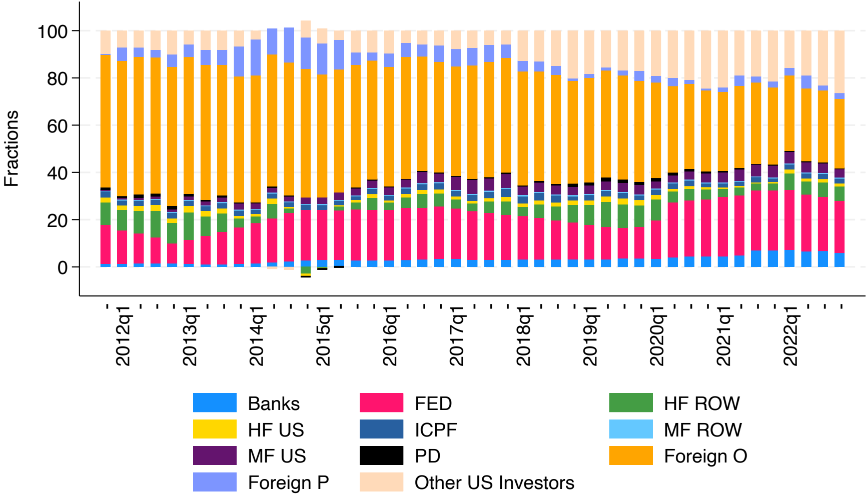
Who Holds What (% of total debt) - Aggregate



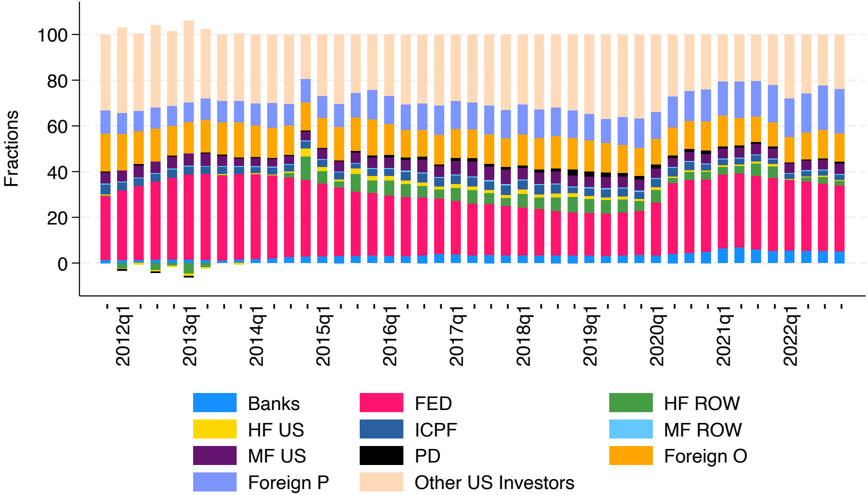
Who Holds What (% of total debt): maturity $\leq$ 1Y



Who Holds What (% of total debt): $1Y < \text{maturity} \leq 5Y$



Who Holds What (% of total debt): maturity > 5Y



Investor Demand According to Portfolio Optimization

- Three maturities, τ_k, $k \in \{1,2,3\}$, $Z_t^\iota = (Z_t^\iota(\tau_1), Z_t^\iota(\tau_2), Z_t^\iota(\tau_3))$. Investor ι solves

$$\max_{Z_t^\iota, \tilde{Z}_t} \mathbb{E}_t^\iota[W_{t+1}^j] - \frac{\gamma^\iota}{2}\mathbb{V}_t^\iota(W_{t+1}) + \underbrace{V^\iota(Z_t^\iota)}_{\text{non-pecuniary}}$$

$$W_{t+1} = W_t(1+r_t) + \sum_{k=1}^{3} Z_t^\iota(\tau_k)(R_{t+1}^{(\tau_k)} - r_t) + \underbrace{\tilde{Z}_t^\iota(\tilde{R}_{t+1}^\iota - r)}_{\text{outside portfolio return}}$$

- Expectation $\mathbb{E}^\iota[R_{t+1}^{(\tau)} - r_t] = \mu_\tau^\iota \cdot \beta_t + \phi_\tau^\iota \cdot y_t$, with yield $y_t = (y_t^{\tau_1}, y_t^{\tau_2}, y_t^{\tau_3})$. Solution:

$$Z_t^\iota = \left(\mathbb{V}^\iota(R_{t+1}, R_{t+1}) + \frac{1}{\gamma^\iota}\bar{V}^\iota\right)^{-1}\left(\frac{1}{\gamma^\iota}\left(\mu^\iota\beta_t + \Phi^\iota y_t + \bar{V}_0^\iota\right) - \mathbb{V}^\iota(R_{t+1}, \tilde{R}_{t+1}^\iota)\tilde{Z}_t^\iota\right).$$

- Expanding the "outside portfolio" as affine in β_t plus a noise term, we get

$$Z_t^\iota = \theta_0^\iota + B^\iota y_t - \theta^\iota \beta_t + u_t^\iota$$

- Note: pure arbitrageurs ($V^\iota = 0$, $\mathbb{E}$ rational) demand **does not directly depend on** y_t.

Demand System

- We estimate demand curves for each sector ι:

$$Z_t^\iota(m) = \theta_0^\iota + b_1^\iota y_t(m) + b_2^\iota y_t(-m) + (b_3^\iota)'\mathbf{x}_t(m) + (b_4^\iota)'\mathbf{Macro}_t + u_t^\iota(m)$$

  - Three maturity buckets: $T \leq 1Y$, $1Y < T \leq 5Y$, and $T > 5Y$.
  - $Z_t^\iota(m)$: dollar value of holdings in maturity bucket m for sector ι, standardized by potential GDP.
  - $y_t(m)$: bond yield.
  - $y_t(-m)$: value-weighted bond yield other maturities.
  - $\mathbf{x}_t(m)$: coupon, maturity, and bid-ask spread.
  - $\mathbf{Macro}_t$: GDP gap, inflation, credit spread, and debt/GDP.

- Challenge: latent demand directly affects yields. Need an instrument for yields.
  - Use extracted pseudo yields (Koijen and Yogo, 2020; Fang, Hardy, and Lewis, 2022)

Instruments on Yields

Following Koijen and Yogo (2020) and Fang, Hardy, and Lewis (2022), we construct "pseudo yields" $\tilde{y}_t(m)$ as instruments:

1. Extract predictable component of demand, $\hat{Z}_t^\iota(m)$, excluding yields:
$$Z_t^\iota(m) = \underbrace{\hat{\theta}_0^\iota + (\hat{b}_3^\iota)'\mathbf{x}_t(m) + (\hat{b}_4^\iota)'\mathbf{Macro}_t}_{\equiv \hat{Z}_t^\iota(m)} + \epsilon_t^\iota(m)$$
2. Extract predicted component of supply, $\hat{S}_t(m)$, by regressing on macro variables.
3. Pseudo yields from equating predictable demand with supply:
$$\sum_\iota \hat{Z}_t^\iota(m) = \frac{\hat{S}_t(m)}{(1+\tilde{y}_t(m))^{\tau(m)}}$$

$\rightarrow$ Valid instrument if (i) macro and bond characteristics exogenous to latent demand and (ii) nonlinear relationship pseudo yields and macro and bond characteristics.

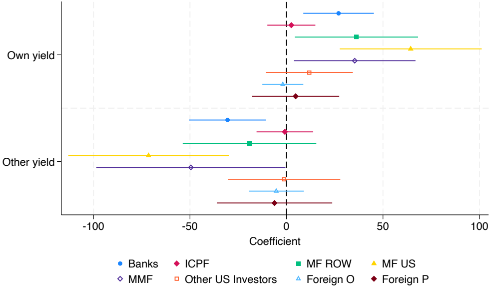
Demand System Results - Granular-Demand Investors

	Banks	ICPF	MF ROW	MF US	MMF	Other US Investors	Foreign O	Foreign P
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$y_t(m)$	63.850**	3.833	6.934*	137.258***	436.596*	172.272	-33.849	32.697
	[26.277]	[11.461]	[3.716]	[47.699]	[236.128]	[199.313]	[115.257]	[94.669]
$y_t(-m)$	-72.167**	-1.247	-3.663	-152.400***	-611.375*	-17.813	-94.278	-42.745
	[28.676]	[13.518]	[4.025]	[53.939]	[367.663]	[257.566]	[154.463]	[125.330]
Coupon Rate	-148.638***	3.053	-4.817	-137.838**	55.752	182.530	-480.953**	-315.103*
	[35.111]	[18.189]	[4.853]	[61.177]	[545.299]	[319.718]	[191.041]	[180.040]
Bid-Ask Spread	7.730	18.664***	3.059**	12.692	136.693	109.723	-102.377**	-65.497
	[7.921]	[4.472]	[1.206]	[16.243]	[140.086]	[76.916]	[46.128]	[56.216]
$\mathbb{1}\{1Y \leq \tau < 5\}$	56.159***	148.746***	12.952***	189.591***		-427.082***	2923.108***	-346.709***
	[15.057]	[4.427]	[2.132]	[26.569]		[122.524]	[91.434]	[83.651]
$\mathbb{1}\{\tau \geq 5\}$	-68.055	182.999***	9.623	36.298		451.302	148.771	44.390
	[47.867]	[20.885]	[7.022]	[91.367]		[413.365]	[226.244]	[186.195]
Credit Spread	15.144	-12.095	0.784	-37.701	-512.281**	286.080	95.977	-30.513
	[20.288]	[13.631]	[2.489]	[40.149]	[202.541]	[185.470]	[90.280]	[130.369]
Debt/GDP	648.082***	-7.771	41.743***	-18.509	5592.173***	2142.833**	-1806.284***	651.782
	[79.844]	[48.167]	[10.595]	[135.214]	[1277.801]	[919.753]	[572.490]	[536.095]
GDP Gap	11.000***	-4.501**	1.424***	12.121**	-75.617***	-9.814	-10.512	8.537
	[3.708]	[1.885]	[0.460]	[5.146]	[21.914]	[29.890]	[17.207]	[17.759]
Core Inflation	16.814**	-0.440	-2.254***	-3.223	59.070	-13.744	-74.315*	3.339
	[6.870]	[3.300]	[0.854]	[11.134]	[95.780]	[49.601]	[40.866]	[33.921]
Observations	135	135	135	135	45	135	135	135
Kleibergen-Paap Statistic (*first stage*)	11.13	11.13	11.13	11.13	4.27	11.13	11.13	11.13

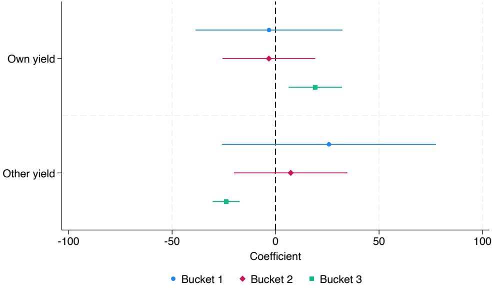
Demand System Results - Fed

	$\mathbb{1}\{\tau < 1Y\}$	$\mathbb{1}\{1Y \leq \tau < 5Y\}$	$\mathbb{1}\{\tau \geq 5Y\}$
	(1)	(2)	(3)
$y_t(m)$	-14.733	-49.318	385.678**
	[100.514]	[208.133]	[157.594]
$y_t(-m)$	120.213	112.178	-478.703***
	[146.510]	[254.479]	[79.222]
Coupon Rate	-35.947	-2557.515***	246.631
	[186.162]	[256.424]	[248.683]
Bid-Ask Spread	203.700***	102.781	-177.449***
	[59.059]	[75.504]	[65.788]
Credit Spread	24.368	206.475	-231.120*
	[82.169]	[138.053]	[137.150]
Debt/GDP	3643.632***	429.732	4649.721***
	[398.422]	[564.090]	[1020.458]
GDP Gap	-6.980	-16.387	-49.862**
	[7.078]	[14.768]	[22.644]
Core Inflation	46.812	-61.166	155.350***
	[40.232]	[40.724]	[29.301]
Observations	45	45	45
Kleibergen-Paap Statistic (*first stage*)	4.27	9.58	14.67

Demand Elasticities by Investor Type



(a) Granular-demand investors



(b) Fed

Model Setup

- Three types of agents: granular-demand investors, the Fed, and arbitrageurs.
- State of the economy: macro factor β_t and monetary policy rate r_t.
- Macroeconomic dynamics: $\beta_{t+1} = \bar{\beta} + \Phi(\beta_t - \bar{\beta}) + \Sigma^{1/2}\epsilon_{t+1}$.
- Monetary policy rule: $r_{t+1} = \bar{r} + \phi_r'(\beta_{t+1} - \bar{\beta}) + \rho_r r_t + \sigma_r \epsilon_{t+1}^r$.
  - This is a more generalized version of the Taylor rule.
- Treasury supply: $S_t^{(\tau)} = \bar{S}^{(\tau)} + \zeta(\tau)'\beta_t + \zeta_r(\tau) r_t$.

Model Setup

- Non-arbitrageur demand (including the Fed and granular-demand investors)

$$Z_t(\tau) = \theta_0(\tau) - \alpha(\tau)' p_t - \theta(\tau)' \beta_t + u_t(\tau),$$

  where p_t is a vector of log Treasury prices and $u_t(\tau)$ is the latent demand.

- Arbitrageur: maximize mean-variance objective function by trading Treasuries of all maturities. $\max_{\{X_t(\tau)\}, \tilde{X}_t} E_t[W_{t+1}] - \frac{\gamma}{2} Var_t(W_{t+1})$, subject to

$$W_{t+1} = W_t(1 + r_t) \quad + \quad \underbrace{\sum_{\tau=2}^{N} X_t(\tau)(R_{t+1}^{(\tau)} - r_t)}_{\text{Treasury excess return}} \quad + \quad \underbrace{\tilde{X}_t(\tilde{R}_{t+1} - r_t).}_{\text{Outside asset excess return}}$$

- Outside portfolio exposure is spanned by macro factor β_t.

- Treasury market clearing: $Z_t(\tau) + X_t(\tau) = S_t(\tau)$.

A Simplified Model for Intuitions

- We assume $N = 2$: two maturities that represent "short" and "long".
- Non-arbitrageur demand exhibits matrix of demand response to yield

$$\begin{pmatrix} a & -b \\ -b & a \end{pmatrix},$$

so Treasury demand increases in its own yield, but decreases in the other-maturity yield.

- Set $K = 1$ so β_t is a one-dimensional "supply" factor.
- $\phi_r = 0$, $\bar{r} = 0$, $\zeta_r = 0$...

Model Intuition: Decomposition of Treasury Pricing

$$p_t^{(1)} = -r_t$$

$$p_t^{(2)} = -\frac{1+\rho_r+\gamma\sigma_r^2 b}{1+\frac{a}{2}\gamma\sigma_r^2} r_t - \frac{\gamma\sigma_r^2(\zeta(2)+\theta(2))}{1+\frac{a}{2}\gamma\sigma_r^2}\beta_t + \frac{\gamma\sigma_r^2}{1+\frac{a}{2}\gamma\sigma_r^2} u_t(2) + \frac{\frac{1}{2}-\gamma\bar{S}^{(2)}+\gamma\theta_0(2)}{\frac{1}{\sigma_r^2}+\frac{a}{2}\gamma}.$$

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Proposition: *Monetary policy rate r_t plays a dominant role for short-maturity Treasuries, while macro shocks and latent demand shocks become more important for long-maturity Treasuries.*

Model Intuition: Arbitrageur Risk Aversion

Proposition: *Arbitrageur risk aversion* γ *increases the price impact of demand shocks.*

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- $\gamma \to 0$: arbitrageurs are risk neutral and arbitrage to the full extent

$$p_t^{(2)} = -(1+\rho_r)r_t + \frac{1}{2}\sigma_r^2.$$

- $\gamma \to \infty$: so arbitrageurs "drop out" of the market

$$p_t^{(2)} = -\frac{2b}{a}r_t - \frac{2}{a}(\zeta(2)+\theta(2))\beta_t + \frac{2}{a}u_t(2) + \frac{2}{a}(\theta_0(2) - \bar{S}^{(2)}).$$

Model Intuition: Monetary Policy and the Yield Curve

Proposition: *If* $2b/a > 1 + \rho_r$ *(strong cross elasticity), a positive monetary policy shock increases the term premium. If* $2b/a < 1 + \rho_r$ *(weak cross elasticity), the opposite is true.*

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- When short rate increases, we have:
  - Non-arbitrageurs: Cross substitution $\rightarrow \downarrow$ long-term Treasury holdings.
  - Arbitrageurs: $\uparrow$ long-term Treasury holdings $\rightarrow \uparrow$ risk premium.

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- When short rate increases, we have:
  - Non-arbitrageurs: Cross substitution $\rightarrow \downarrow$ long-term Treasury holdings.
  - Arbitrageurs: $\uparrow$ long-term Treasury holdings $\rightarrow \uparrow$ risk premium.

- Opposite to Vayanos and Vila (2021) due to cross elasticity.

- Consistent with positive risk premium response to monetary policy tightening (Bekaert, Hoerova, and Duca (2013); Hanson and Stein (2015); Gertler and Karadi (2015); Drechsler, Savov, and Schnabl (2018); Kekre, Lenel, and Mainardi (2024)).

Model Estimation

- Step 1: We estimate non-arbitrageur, VAR dynamics for macroeconomic variables, monetary policy rule, and Treasury supply from the data 2011–2022. We explicitly obtain demand functions: $Z_t = \theta_0 - \alpha p_t - \theta \beta_t + u_t$.

- Step 2: We estimate remaining parameters to minimize

$$\min_{\{\lambda_{\beta,\beta},\lambda_{\beta,r},\lambda_{r,\beta},\lambda_{r,r},\gamma,\psi,\psi_r\}} \mathbb{E}\left[M \cdot (h - h^o)^2 + \sum_t \sum_\tau (y_t(\tau) - y_t^o(\tau))^2\right],$$

where $y_t^o(\tau)$ is observed yield and h^o is average arbitrageurs' long-term Treasury holding in the data. Set M large to guarantee $h \to h^o$.

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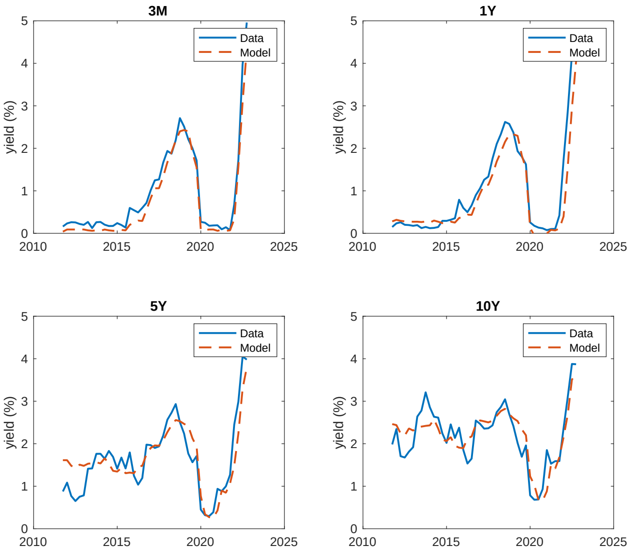
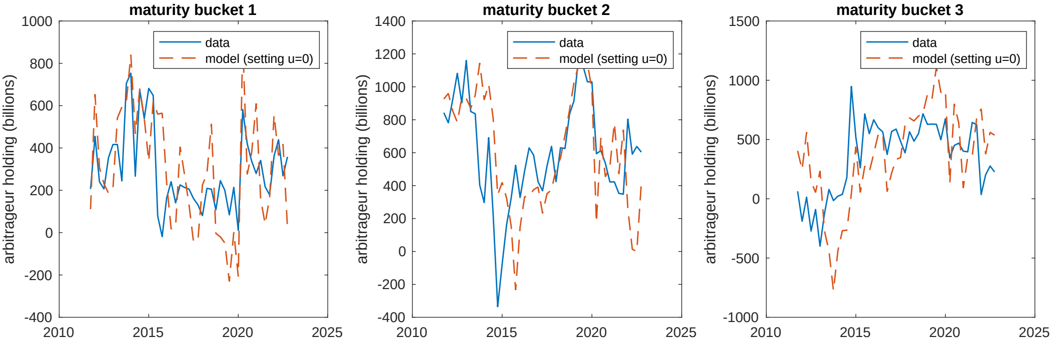
Model Fit on Treasury Yield Dynamics

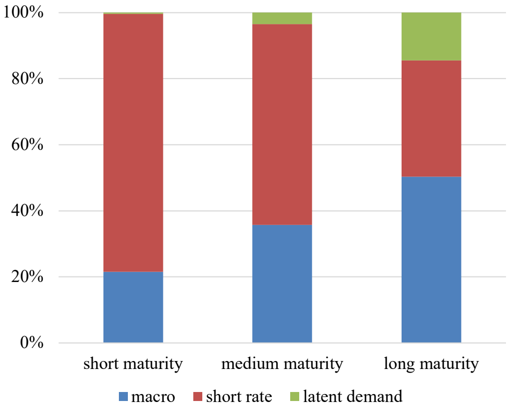


Model Fit on Arbitrageur Holdings

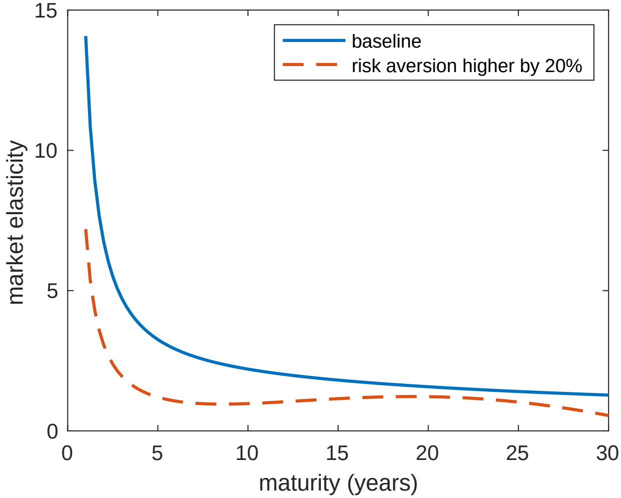


Decomposition of Treasury Pricing: Short rate, Macro, and Latent demand

- Relative contribution of different driving factors, using Shapley R^2 values.

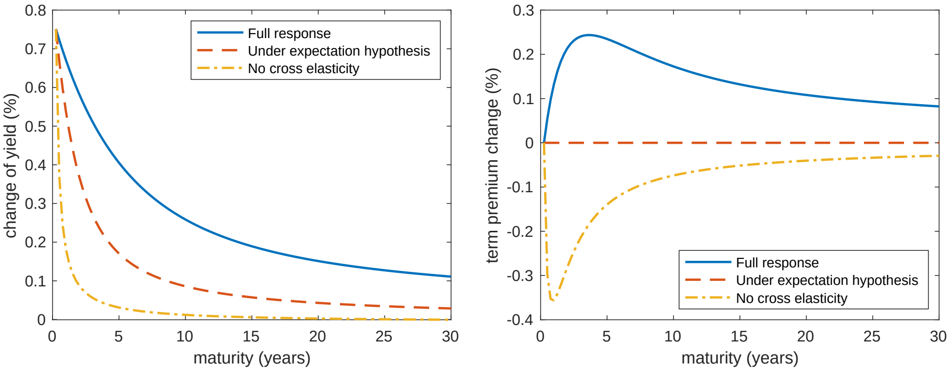


Term Structure of Treasury Market Elasticity



- Aggregate elasticity about 5.
- Higher arbitrageur risk aversion reduces elasticity.
- Much more elastic than stocks and corporate bonds.

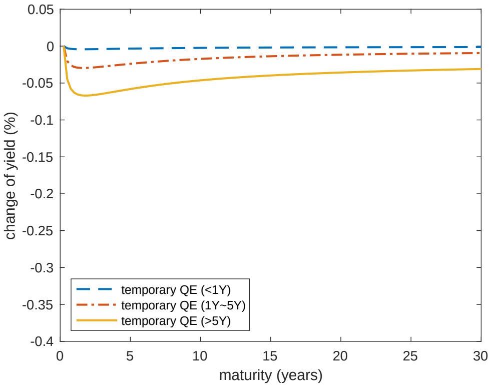
Monetary Policy Response: The Role of Cross Elasticity

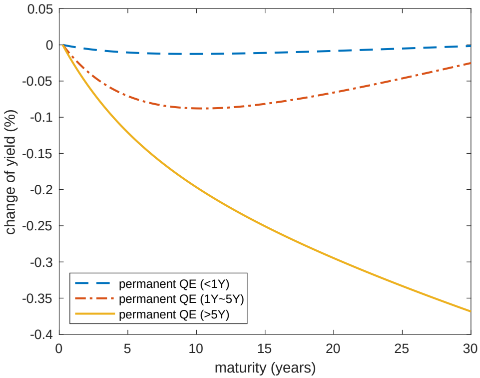


- Higher short-term rate → granular-demand investors reduce long-term holdings (due to cross substitution) → arbitrageur increase holding and term premium rises
- Shutting off cross elasticity, term premium response flips sign.

Quantitative Easing

- We represent QE as shocks to the Fed demand for Treasuries.
  - $100 billion "QE" shock (extra demand) on different maturity buckets.
  - Transitory demand shock (left) v.s. permanent demand shock (right).





Conclusion

- We connect granular demand estimations with arbitrage in an equilibrium model.
- Using a novel dataset of U.S. Treasury holdings, we uncover:
  1. Significant cross-elasticity for most investors.
  2. Fed's long-term Treasury holdings significantly react to Treasury yields controlling for macro.
- We estimate an equilibrium model of U.S. Treasuries with granular-demand investors, the Fed, and arbitrageurs.
  1. Treasury market is elastic because of low estimated arbitrageur risk aversion.
  2. Positive term premium response to monetary policy hike, due to cross elasticity.
  3. Power of QE policy hinges on perceived persistence of Fed purchases.