A Unified Theory of the Term-Structure and Monetary Stabilization

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Example: IS equation with 3 maturities (short-term, 10 years, 30 years)

$$\underbrace{\hat{c}_t}_{\downarrow} = \mathbb{E}_t \left[\hat{c}_{t+1} - \left(\underbrace{\hat{r}^S_{t+1}}_{\uparrow} - \hat{\pi}_{t+1} \right) \right]$$

where

$$\hat{r}^S_{t+1} = \underbrace{i_t}_{\text{Policy rate}} + w_t^{10} \cdot \left(\hat{r}^{10}_{t+1} - i_t \right) + w_t^{30} \cdot \left(\hat{r}^{30}_{t+1} - i_t \right)$$

Up to a first-order, portfolio demand $\left(w_t^{10}, w_t^{30}\right)$ depend on relative returns:

$$\underbrace{w_t^{10}}_{\uparrow} = w^{10} \left(\underbrace{i_t}_{\downarrow}, \underbrace{\hat{r}^{10}_{t+1}}_{\uparrow}, \underbrace{\hat{r}^{30}_{t+1}}_{\downarrow} \right)$$

- Demand elasticity with respect to returns is **finite**: market segmentation
- With $i_t \downarrow$, we have $(w_t^{10} \uparrow,\ w_t^{30} \uparrow)$, leading to $(\hat{r}_t^{10} \downarrow,\ \hat{r}_t^{30} \downarrow)$ (i.e., portfolio re-balancing), thereby $\hat{r}^S_{t+1} \downarrow$, but not one-to-one
- Then real effects: $\hat{c}_t \uparrow$

This paper

A quantitative macroeconomic framework that incorporates

1. The general equilibrium term-structure of interest rates
2. Multiple asset classes (government bonds and private bond)
3. Endogenous portfolio shares among different kinds of assets
4. Market segmentation across different maturities bonds (how?: methodological contribution + estimation)

that makes LSAPs work in theory (a demand curve for each maturity bond slopes down)

Plus:

5. Government and central bank's explicit balance sheets
6. A micro-founded welfare criterion

which are necessary for quantitative policy experiments (e.g., conventional vs. unconventional monetary policies)

Big Findings (Conventional vs. Unconventional)

Unconventional monetary policy (e.g., yield-curve-control (YCC)) is powerful in terms of stabilization in both normal and ZLB

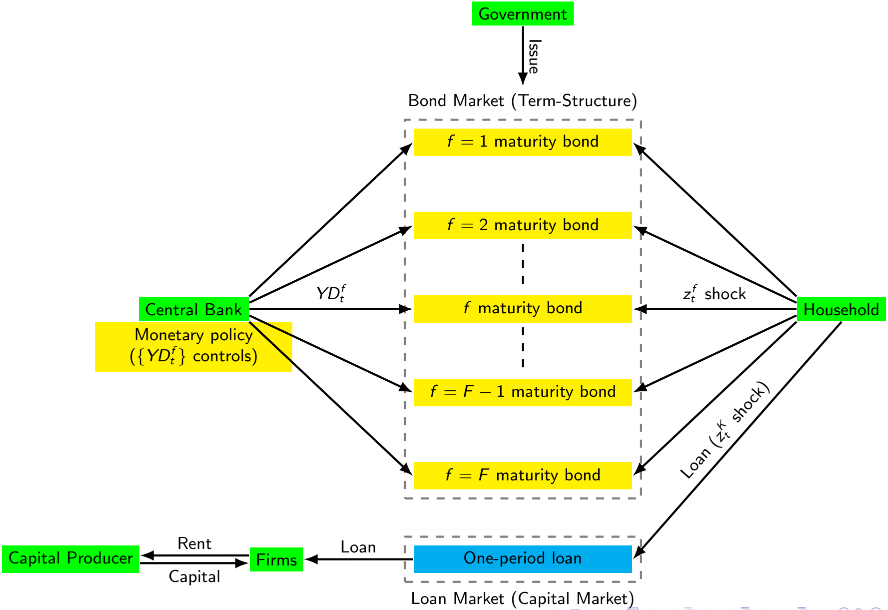
- As a drawback, the economy experiences longer ZLB regimes

Mechanism: long term yields$\downarrow$ $\Longrightarrow$ portfolio shares of short term$\uparrow$ $\Longrightarrow$ short yields$\downarrow$ $\Longrightarrow$ ZLB duration$\uparrow$ $\Longrightarrow$ more reliance on LSAPs

'ZLB + LSAPs addicted economy'

Literature

The model: environment



The representative household's problem (given B_0):

$$\max_{\{C_{t+j},N_{t+j}\}} \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left[\log\left(C_{t+j}\right) - \left(\frac{\eta}{\eta+1}\right) \left(\frac{N_{t+j}}{\bar{N}_{t+j}}\right)^{1+\frac{1}{\eta}} \right]$$

subject to

Loans

f-maturity rate

Loan rate

$$C_t + \frac{L_t}{P_t} + \frac{\sum_{f=1}^{F} B_t^{H,f}}{P_t} = \frac{\sum_{f=0}^{F-1} R_t^f \; B_{t-1}^{H,f+1}}{P_t} + \frac{R_t^K \; L_{t-1}}{P_t} + \int_0^1 \frac{W_t(\nu)N_t(\nu)}{P_t}\, d\nu + \frac{\Lambda_t}{P_t}$$

Nominal bond purchase
(*f*-maturity)

where

- ν: intermediate firm index such that:

$$N_t = \left(\int_0^1 N_t(\nu)^{\frac{\eta+1}{\eta}}\, d\nu\right)^{\frac{\eta}{\eta+1}}$$

- Q_t^f is the nominal price of *f*-maturity bond with:

$$(\text{Return})\; R_t^f = \frac{Q_t^f}{Q_{t-1}^{f+1}}, \quad (\text{Yield})\; YD_t^f = \left(\frac{1}{Q_t^f}\right)^{\frac{1}{f}}$$

Total savings: $S_t = B_t^H + L_t = \sum_{f=1}^{F} B_t^{H,f} + L_t$

Usual bond allocation problem (Ricardian):

$$\max \sum_{f=1}^{F} \mathbb{E}_t \left[Q_{t,t+1} R_{t+1}^{f-1} B_t^{H,f} \right] \quad \text{s.t.} \quad \sum_{f=1}^{F} B_t^{H,f} = B_t^H, \quad B_t^{H,f} \geq 0$$

which gives (in equilibrium):

$$\mathbb{E}_t \left[Q_{t,t+1} R_{t+1}^{f-1} \right] = \mathbb{E}_t \left[Q_{t,t+1} R_{t+1}^{0} \right], \quad \forall f \quad \Longrightarrow \quad \boxed{\mathbb{E}_t[\widehat{R}_{t+1}^{f-1}] = \widehat{R}_{t+1}^{0}}$$

'Expectation hypothesis'

Our approach (Non-Ricardian):

- Split the household into a family $m \in [0,1]$, each of which decides whether to invest in bonds or loan, subject to expectation shock $\sim$ Fréchet
- A bond family m is split into members $n \in [0,1]$, each of whom decides maturity f to invest in, subject to expectation shock $\sim$ Fréchet

Bond portfolio (e.g., Eaton and Kortum (2002))

$$\lambda_t^{HB,f} \equiv \left(\frac{z_t^f \mathbb{E}_t \left[Q_{t,t+1} R_{t+1}^{f-1} \right]}{\Phi_t^B} \right)^{\kappa_B}$$

f-maturity share

- Deviate from expectation hypothesis $\Longrightarrow$ $\exists$downward-sloping demand curve after log-linearization with finite demand elasticity
- Shape parameter κ_B: (inverse of) a degree of bonds market segmentation
- $z_t^f = 1$, $\kappa_B \to \infty$, then $\mathbb{E}_{m,n,t} \to \mathbb{E}_t$ (i.e., rational expectations)

Effective bond market rates

$$R_{t+1}^{HB} = \sum_{f=0}^{F-1} \lambda_t^{HB,f+1} R_{t+1}^f$$

Microfoundation (bond)

Loan share (e.g., Eaton and Kortum (2002))

$$\lambda_t^K = \left(\frac{z_t^K \mathbb{E}_t \left[Q_{t,t+1} R_{t+1}^K \right]}{\Phi_t^S} \right)^{\kappa_S}$$

Loan share

- $\exists$downward-sloping demand curve after log-linearization (for loan and bonds)
- Shape parameter κ_S: (inverse of) a degree of market segmentation between government bonds vs loan

Effective savings rate: governs intertemporal substitution

$$\begin{aligned} R_t^S &= \left(1 - \lambda_{t-1}^K\right) R_t^{HB} + \lambda_{t-1}^K R_t^K \\ &= \left(1 - \lambda_{t-1}^K\right) \sum_{f=0}^{F-1} \lambda_{t-1}^{HB,f+1} R_t^f + \lambda_{t-1}^K R_t^K \end{aligned}$$

Enters Euler equation

Microfoundation (loan)

Bond market equilibrium:

$$B_t^{H,f} + B_t^{G,f} + B_t^{CB,f} = 0, \quad \forall f = 1, \ldots, F$$

Monetary
policy

Central bank: monetary policy through balance sheet adjustments

- Conventional: Taylor rules on YD_t^1 $\left(\text{only adjusting } B_t^{CB,1}\right)$
- Yield-curve-control (YCC): Taylor rules on $\left\{YD_t^f\right\}$ $\left(\text{adjusting } \left\{B_t^{CB,f}\right\}\right)$
- Subject to zero lower bound (ZLB)

Conventional | Unconventional | Capital Producer, Firms, and Government

Steady-state U.S. calibrated yield curve (up to 30 years)

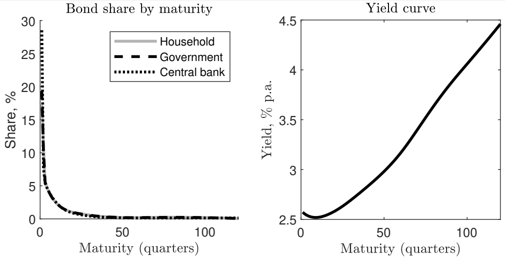


Figure: Steady-state bond portfolios of household, government, and central bank and the resultant yield curve (December 2002 - June 2007)

Estimation: $\kappa_B = 10$ from the aggregate bond portfolio data ▸▸ Estimation

Calibration: given $\kappa_B = 10$ and $\kappa_S = 6$ (from Kekre and Lenel (2023))

- $\{z^f\}_{f=1}^F$ (i.e., maturity preference for a maturity-f) $\Longrightarrow$ yield curve slopes
- z^K (i.e., preference for private loan) $\Longrightarrow$ the yield curve level
- **Result**: $z^1 = 1 >> z^f$ for $f \geq 2$ (e.g., safety - liquidity premium)

▸▸ Supply effects ▸▸ Demand effects ▸▸ Deficit ratio

Short-run analysis (Impulse-responses)

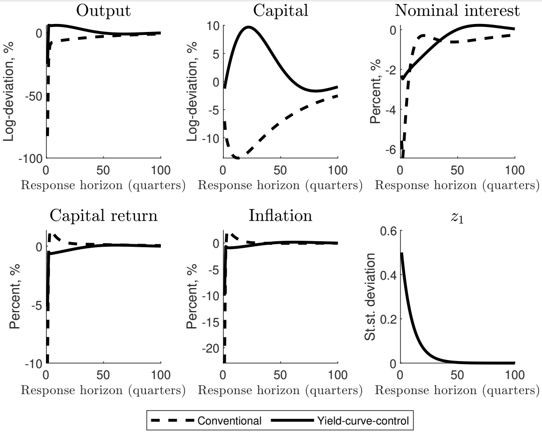


Figure: Impulse response to z_t^1 shock

With conventional policy

- Short yields↓ $\Longrightarrow$ other yields, capital return, and wage↓ $\Longrightarrow$ output↓ (labor supply↓) and inflation↓

With yield-curve-control (YCC): stabilizing (filling gaps in bond demand)

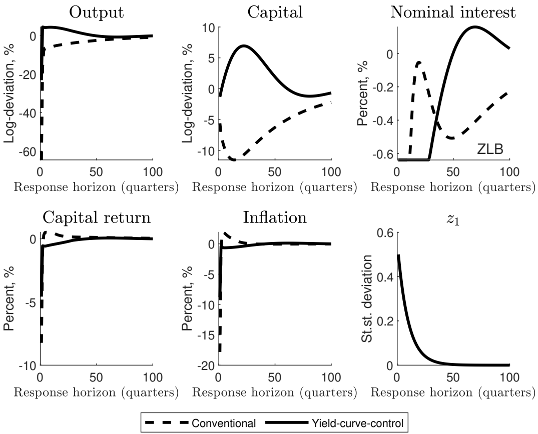


Figure: ZLB impulse response to z_t^1 shock

With yield-curve-control (YCC): stabilizing (filling gaps in bond demand)

- But duration of ZLB episodes↑

Long-term rates↓ $\Longrightarrow$ ZLB duration↑

ZLB IRF (z_t^K)

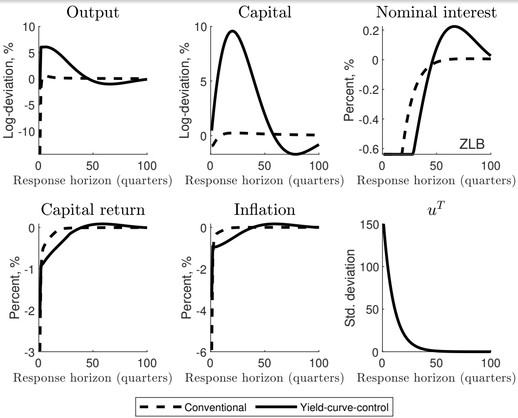


Figure: ZLB impulse response to ϵ_t^T shock

With conventional policy: non-Ricardian

- Tax↑ $\Longrightarrow$ bond supply↓ $\Longrightarrow$ ZLB $\Rightarrow$ recessions (Caballero and Farhi, 2017)

With yield-curve-control (YCC): stabilizing

- But duration of ZLB episodes↑

We also consider:

- Mixed policy: central bank starts controlling long-term rates only when FFR hits ZLB, thus YCC only at the ZLB

	Conventional	Yield-Curve-Control	Mixed Policy
Mean ZLB duration	4.5533 quarters	6.2103 quarters	5.5974 quarters
Median ZLB duration	3 quarters	3 quarters	2 quarters
ZLB frequency	15.9596%	13.4242%	17.4141%
Welfare	-1.393%	-1.2424%	-1.3662%

Table: Policy comparisons (ex-ante)

ZLB duration: Conventional $<$ Mixed $<$ YCC

ZLB frequency: YCC $<$ Conventional $<$ Mixed

Welfare: Conventional $<$ Mixed $<$ YCC

Thank you very much!

(Appendix)

- The term-structure and macroeconomy: Ang and Piazzesi (2003), Rudebush and Wu (2008), Bekaert et al. (2010)
- Central bank's endogenous balance sheet size as an another form of monetary policy: Gertler and Karadi (2011), Cúrdia and Woodford (2011), Christensen and Krogstrup (2018, 2019), Karadi and Nakov (2021), Sims and Wu (2021)
- Zero lower bound (ZLB) and issuance of safe bonds: Swanson and Williams (2014), Caballero and Farhi (2017), Caballero et al. (2021)
- Welfare criterion with a trend inflation: Coibion et al. (2012)
- Preferred-habitat term-structure (and limited risk-bearing): Greenwood et al. (2020), Vayanos and Vila (2021), Gourinchas et al. (2021), Kekre et al. (2023)
- Preferred-habitat term-structure and the real economy in New-Keynesian macroeconomics: Ray (2019), Droste, Gorodnichenko, and Ray (2021)

Our paper: general equilibrium term-structure (without relying on factor models) + balance sheet quantities of government and central bank + yield-curve-control + novel way to generate and estimate market segmentation

Bond family m: a member n has the following expectation shock:

$$\mathbb{E}_{m,n,t}\left[Q_{t,t+1}R^{f-1}_{t+1}\right] = z^f_{n,t}\cdot\mathbb{E}_t\left[Q_{t,t+1}R^{f-1}_{t+1}\right],\quad \forall f=1,\dots,F$$

with $z^f_{n,t}$ follows a Fréchet distribution with location parameter 0, scale parameter z^f_t, and shape parameter κ_B

Aggregation (Eaton and Kortum (2002))

$$\begin{aligned}\lambda^{HB,f}_t &\equiv \mathbb{P}\left(\mathbb{E}_{m,n,t}\left[Q_{t,t+1}R^{f-1}_{t+1}\right] = \max_j\left\{\mathbb{E}_{m,n,t}\left[Q_{t,t+1}R^{j-1}_{t+1}\right]\right\}\right)\\ &= \left(\frac{z^f_t\mathbb{E}_t\left[Q_{t,t+1}R^{f-1}_{t+1}\right]}{\Phi^B_t}\right)^{\kappa_B}\end{aligned}$$

f-maturity share

- Deviate from expectation hypothesis $\Longrightarrow$ $\exists$downward-sloping demand curve after log-linearization with finite demand elasticity
- Shape parameter κ_B: (inverse of) a degree of bonds market segmentation

Effective bond market rates

$$R^{HB}_{t+1} = \sum_{f=0}^{F-1}\lambda^{HB,f+1}_t R^f_{t+1}$$

Go back

Loan vs. bond decision: a family m solves the following problem

$$\max \ \mathbb{E}_t\left[Q_{t,t+1}R^{HB}_{t+1}B^H_{m,t}\right] + z^K_{m,t}\cdot\mathbb{E}_t\left[Q_{t,t+1}R^K_{t+1}L_{m,t}\right] \quad \text{s.t.}$$

$$B^H_{m,t} + L_{m,t} = S_t, \quad B^H_{m,t}\geq 0, \quad \text{and} \quad L_{m,t}\geq 0$$

with $z^K_{m,t}$ follows a Fréchet distribution with location parameter 0, scale parameter z^K_t, and shape parameter κ_S

Aggregation (Eaton and Kortum (2002))

Loan share

$$\lambda^K_t = \left(\frac{z^K_t\mathbb{E}_t\left[Q_{t,t+1}R^K_{t+1}\right]}{\Phi^S_t}\right)^{\kappa_S}$$

- $\exists$downward-sloping demand curve after log-linearization (for loan and bonds)
- Shape parameter κ_S: (inverse of) a degree of market segmentation between government bonds vs loan

Effective savings rate: governs intertemporal substitution

$$R^S_t = \left(1-\lambda^K_{t-1}\right)R^{HB}_t + \lambda^K_{t-1}R^K_t$$

$$= \left(1-\lambda^K_{t-1}\right)\sum_{f=0}^{F-1}\lambda^{HB,f+1}_{t-1}R^f_t + \lambda^K_{t-1}R^K_t$$

Go back

Conventional monetary policy

Under the conventional monetary policy, central banks set Taylor rules on YD_t^1 (i.e., the shortest yield) while not manipulating longer term bonds holdings

- Long-term yields fluctuate endogenously (in response to shocks + changes in short-term rate)

$$R_{t+1}^0 \equiv YD_t^1 = \max\left\{ YD_t^{1*},\ \underbrace{1}_{\text{ZLB}} \right\}$$

$$YD_t^{1*} = \overline{YD}^1 \left(\frac{YD_{t-1}^{1*}}{\overline{YD}^1}\right)^{\rho_1} \left(\frac{YD_{t-2}^{1*}}{\overline{YD}^1}\right)^{\rho_2} \left(\underbrace{\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\gamma_\pi^1} \left(\frac{Y_t}{\bar{Y}}\right)^{\gamma_y^1}}_{\text{Targeting}} \cdot \exp\left(\underbrace{\tilde{\varepsilon}_t^{YD^1}}_{\text{MP shock } (f=1)}\right) \right)^{1-(\rho_1+\rho_2)}$$

$$\underbrace{\frac{B_t^{CB,f}}{A_t \bar{N}_t P_t} = \frac{\overline{B^{CB,f}}}{A\bar{N}P}}_{\text{Normalized holding of } f>1 \text{ fixed}} \qquad \forall f = 2, \ldots, F$$

Go back

Unconventional monetary policy: yield-curve-control (YCC)

In the unconventional monetary policy case, central bank targets all yields along the yield curve, assuming the Taylor-type rule for each maturity yield

- Back out the needed purchases of each maturity $\forall f$, which are endogenous

$$R^0_{t+1} \equiv YD^1_t = \max\left\{ YD^{1*}_t ,\ \underbrace{1}_{\text{ZLB}} \right\}$$

$$YD^{1*}_t = \overline{YD}^1 \left(\frac{YD^{1*}_{t-1}}{\overline{YD}^1}\right)^{\rho_1} \left(\frac{YD^{1*}_{t-2}}{\overline{YD}^1}\right)^{\rho_2} \left(\underbrace{\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\gamma^1_\pi} \left(\frac{Y_t}{\bar{Y}}\right)^{\gamma^1_y}}_{\text{Targeting}} \cdot \exp\left(\underbrace{\tilde{\varepsilon}^{YD^1}_t}_{\text{MP shock } (f=1)} \right) \right)^{1-(\rho_1+\rho_2)}$$

$$YD^{f*}_t = \overline{YD}^f \left(\frac{YD^{f*}_{t-1}}{\overline{YD}^f}\right)^{\rho_1} \left(\frac{YD^{f*}_{t-2}}{\overline{YD}^f}\right)^{\rho_2} \left(\underbrace{\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\gamma^f_\pi} \left(\frac{Y_t}{\bar{Y}}\right)^{\gamma^f_y}}_{\text{Targeting}} \cdot \exp\left(\underbrace{\tilde{\varepsilon}^{YD^f}_t}_{\text{MP shock } (\forall f \geq 2)} \right) \right)^{1-(\rho_1+\rho_2)}$$

Go back

Capital producer: competitive producer of capital (lend capital to intermediate firms at price P_t^K)

Firms: standard with Cobb-Douglas production (pricing à la Calvo (1983))

- One financial friction: firms need secure loans from the household to operate: for simplicity, borrow γ portion of the revenue it generates

$$\underbrace{L_t(\nu)}_{\text{Loan of firm } \nu} \geq \gamma(1+\zeta^F)P_t(\nu)Y_t(\nu), \forall \nu$$

Government: with the following budget constraint

$$\frac{B_t^G}{P_t} = \frac{R_t^G B_{t-1}^G}{P_t} - \left[\underbrace{\zeta_t^G}_{\frac{G_t}{Y_t}\text{ (Exogenous)}} + \underbrace{\zeta^F}_{\text{Production subsidy}} - \underbrace{\zeta_t^T}_{\frac{T_t}{Y_t}\text{ (Exogenous)}} \right] Y_t, \quad R_t^G = \sum_{f=0}^{F-1} \underbrace{\lambda_{t-1}^{G,f+1}}_{\text{(Exogenous)}} R_t^f$$

- **Government**: a natural issuer of the entire bond market

From portfolio equations:

$$\lambda_t^{HB,f} \equiv \mathbb{P}\left(\mathbb{E}_{m,n,t}\left[Q_{t,t+1}R_{t+1}^{f-1}\right] = \max_j\left\{\mathbb{E}_{m,n,t}\left[Q_{t,t+1}R_{t+1}^{j-1}\right]\right\}\right)$$

$$= \left(\frac{z_t^f\mathbb{E}_t\left[Q_{t,t+1}R_{t+1}^{f-1}\right]}{\Phi_t^B}\right)^{\kappa_B}$$

f-maturity share

leading to:

$$\log\left(\lambda_t^{H,f}\right) - \log\left(\lambda_t^{H,l}\right) = \alpha^{fl} + \kappa_B \cdot E_t\left[r_{t+1}^{f-1} - r_{t+1}^{l-1}\right] + \varepsilon_t^{fl} \qquad (1)$$

Jordà local projection:

$$\log\left(\lambda_{t+h}^{H,f}\right) - \log\left(\lambda_{t+h}^{H,l}\right) = \alpha_h^{fl} + \kappa_{B,h} \cdot \left[yd_t^f - yd_t^l\right] + \mathbf{x_t'}\beta_\mathbf{h}^\mathbf{fl} + \varepsilon_{t+h}^{fl},\ h \geq 0\ ,$$

- Long maturity: $f = 5 \sim 10$ years and short: $l = 15 \sim 90$ days (bunching) for portfolio shares and use $f = 7$ years and $l = 1$ month for yields
- Instrument $yd_t^f - yd_t^l$ with $yd_{t-1}^f - yd_{t-1}^l$ ($\perp$ demand shocks, e.g., z_t^f, z_t^l)
- Control variables (e.g., lagged $\log\left(\lambda_{t-1}^{H,f}\right) - \log\left(\lambda_{t-1}^{H,l}\right)$ for seriel correlation)

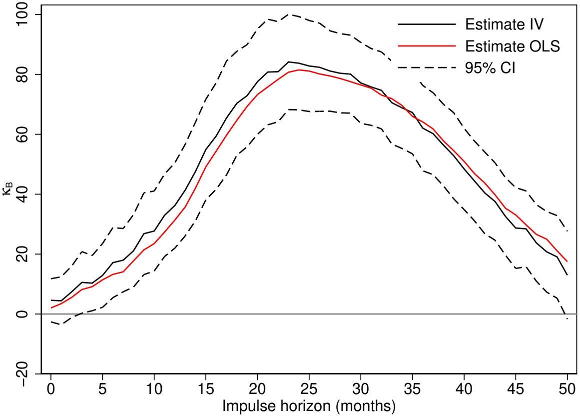


Figure: Impulse-Response to a shock in the yield spread, $yd_t^f - yd_t^l$. The figure presents the coefficient estimates for the bond portfolio elasticity, κ_B. The solid black line illustrates the estimate from the instrumental variables (IV) regression, with dashed lines indicating the 95% robust confidence intervals. The red line exhibits alternative OLS estimates. The sample period is from 2003m3 to 2019m3.

Go back

Government's bond supply effects

Go back

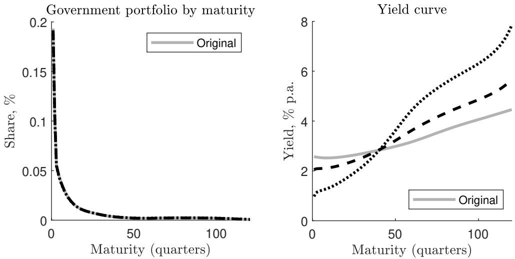


Figure: Government's bond issuance portfolio and yield curve

- Government's supply of f-maturity bond↑ $\Longrightarrow$ its yield↑ (i.e., price effect)
- Similar to Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood and Vayanos (2014) in the long run

Go back

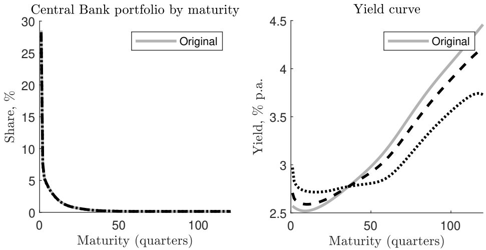


Figure: Central bank's bond demand portfolio and yield curve

- **Segmented** markets $\Longrightarrow$ QE matters in the long run

Go back

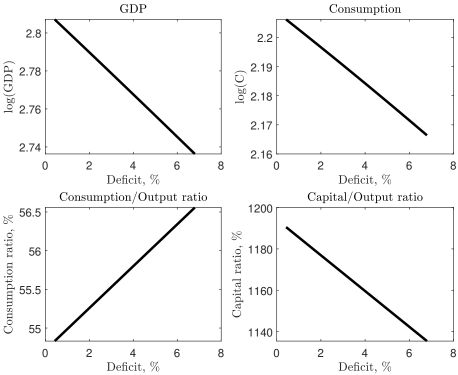


Figure: Variations in a deficit ratio $\zeta_t^G + \zeta^F - \zeta_t^T$

A higher deficit ratio $\Longrightarrow$ depressed economy (for $R^G\downarrow$)

Go back

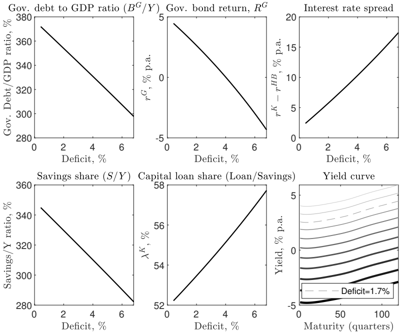


Figure: Variations in a deficit ratio $\zeta_t^G + \zeta^F - \zeta_t^T$

A higher deficit ratio $\Longrightarrow$ depressed economy (for $R^G\downarrow$)

- An entire yield curve$\downarrow$

ZLB impulse response to z_t^K

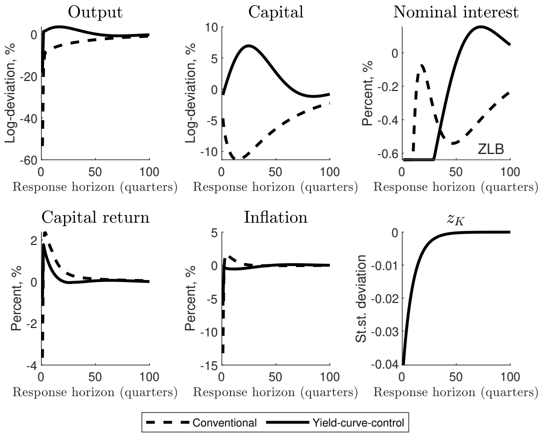


Figure: ZLB impulse response to z_t^K shock

With yield-curve-control (YCC): stabilizing (filling gaps in bond demand)

- But duration of ZLB episodes↑

  Long-term rates↓ $\Longrightarrow$ ZLB duration↑

Go back

Impulse-response to an exogenous tax hike shock

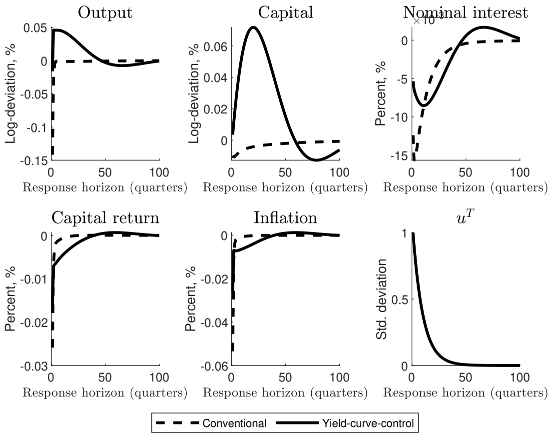


Figure: Impulse response to ϵ_t^T shock

Tax↑ $\Longrightarrow$ bond supply↓ $\Longrightarrow$ yields↓, loan rates↓, and wages↓ (i.e., real effects)

- The yield-curve-control (YCC): stabilizing

Go back