A Unified Theory of the Term-Structure and Monetary Stabilization

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Bernanke (2014): "QE works in practice but not in theory"

Blanchard (2016): "Solution is to introduce two interest rates, the policy rate set by the central bank in the LM equation and the rate at which people and firms can borrow, which enters the IS equation, and then to discuss how the financial system determines the spread between the two."

1. A need for a framework addressing Bernanke (2014)
   - Need for a deviation from the 'expectation hypothesis'

     $\Longrightarrow$ quantity matters!

2. Addressing Blanchard (2016)
   - Term-structure + private capital market needed

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

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

Up to a first-order, portfolio demand (w^{10}_t, w^{30}_t) depend on relative returns:

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

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

A quantitative macroeconomic framework that incorporates

1. **The general equilibrium term-structure of interest rates**
2. **Multiple asset classes (government bonds vs. private bond)**
3. **Endogenous portfolio shares among different kinds of assets**

all of which address Blanchard (2016)

4. **Market segmentation across different maturities (how?: methodological contribution)**

that makes LSAPs work in theory (a demand curve for each maturity bond slopes down) $\Longrightarrow$ addressing Bernanke (2014)

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

which are necessary for quantitative policy experiments (ex. conventional vs. unconventional monetary policies)

What we do + findings

1. **Provide** an efficient way to generate the market segmentation across bonds of different maturities based on Eaton and Kortum (2002)

   - Each atomic investor subject to some expectation shock $\sim$ Fréchet: these shocks have a structural meaning (e.g., liquidity premium)
   - $\exists$Downward-sloping demand curve for each bond of different maturities
   - Estimate the demand elasticity for the Treasury bonds based on macro data

2. **Compare conventional** monetary policy where

   - Central bank adjusts its balance sheet holding of the shortest-term bond to control the shortest-term yield
   - The shortest-term yield follows the Taylor rule (targeting business cycle)

   with the **unconventional** monetary policy where

   - Central bank adjusts its entire bond portfolio along the yield curve to control yields (yields of which maturities to be controlled: chosen by central bank)
   - Controlled yields follow the Taylor rule (targeting business cycle)
   - Similar to a complete **yield-curve-control (YCC)** policy

Big Findings (Conventional vs. Unconventional)

1. Quantity matters! (confirm results in Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood and Vayanos (2014) in theory)
2. Unconventional monetary policy is very powerful in terms of stabilization in both normal and ZLB periods
3. As a drawback, the economy gets addicted to its power under ZLB regimes

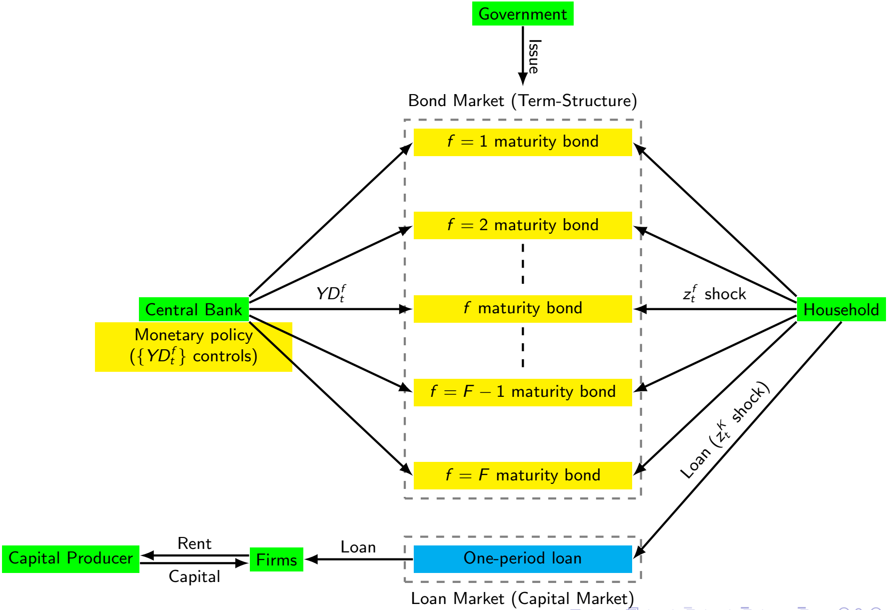
Why?: long term yields$\downarrow$ $\Longrightarrow$ downward pressure on short term yields$\downarrow$ $\Longrightarrow$ ZLB duration$\uparrow$ $\Longrightarrow$ more reliance on LSAPs

: from the household's endogenous portfolio choices

'ZLB+LSAPs addicted economy'

Literature

The Model


Government
Issue
Bond Market (Term-Structure)
$f = 1$ maturity bond
$f = 2$ maturity bond
f maturity bond
$f = F - 1$ maturity bond
$f = F$ maturity bond
Central Bank
YD_t^f
Monetary policy
($\{YD_t^f\}$ controls)
Household
z_t^f shock
Loan (z_t^K shock)
Capital Producer
Rent
Capital
Firms
Loan
One-period loan
Loan Market (Capital Market)

The model: household

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

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

Nominal bond purchase (f-maturity)

where

- ν: intermediate firm index such that:

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

- 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):

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

'Expectation hypothesis'

$\Longrightarrow$ quantity does not matter!

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'Expectation hypothesis'

$\Longrightarrow$ quantity does not matter!

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

$$\mathbb{E}_{m,n,t}\left[Q_{t,t+1}R_{t+1}^{f-1}\right] = z_{n,t}^{f} \cdot \mathbb{E}_{t}\left[Q_{t,t+1}R_{t+1}^{f-1}\right], \quad \forall f = 1, \ldots, F$$

with $z_{n,t}^{f}$ follows a Fréchet distribution with location parameter 0, scale parameter z_{t}^{f}, and shape parameter κ_B

- Note: $z_t^f = 1$, $\kappa_B \to \infty$, then $\mathbb{E}_{m,n,t} \to \mathbb{E}_t$ (i.e., rational expectations)

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Aggregation (Eaton and Kortum (2002))

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

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

f-maturity share

- 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

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

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

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$$= \left(\frac{z^f_t \mathbb{E}_t\left[Q_{t,t+1}R^{f-1}_{t+1}\right]}{\Phi^B_t}\right)^{\kappa_B}$$

f-maturity share

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Effective bond market rates

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

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

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

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Aggregation (Eaton and Kortum (2002))

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

Loan share

- ∃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

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

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

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Aggregation (Eaton and Kortum (2002))

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

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

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

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

Capital Producer, Firms, and Government

Bond market equilibrium:

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

Depends on monetary policy ($B_t^{H,f}$)

Monetary policy ($B_t^{CB,f}$)

- **Central bank**: balance sheet adjustment $\Longleftrightarrow$ monetary policy

Market clearing:

$$C_t = (1 - \zeta_t^G) Y_t + (1 - \delta) K_t - K_{t+1}.$$

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)

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

ZLB

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

MP shock ($f = 1$)

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

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

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

ZLB

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

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MP shock ($\forall f \geq 2$)

Steady-state (long-run) analysis

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

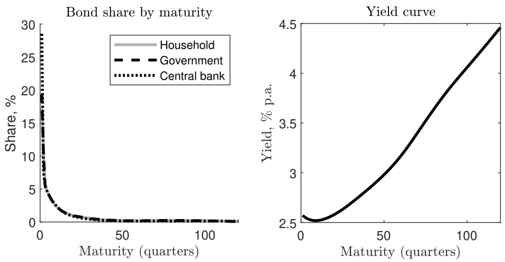

Figure: Steady-state bond portfolios of household, government, and central bank and the resultant yield curve (December 2002 - June 2007)

1. **Estimation**: $\kappa_B = 10$ from the aggregate bond portfolio data ▶▶ Estimation
2. **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): matches the yield curve slope; z^K (i.e., preference for private loan): matches its level
   - Our private loan rate $R^K = 8.12\%$ annually $\simeq$ Moody's seasoned Baa corporate bond average yields
   - **Result**: $z^1 = 1 >> z^f$ for $f \geq 2$ (e.g., safety - liquidity premium)

Government's bond supply effects

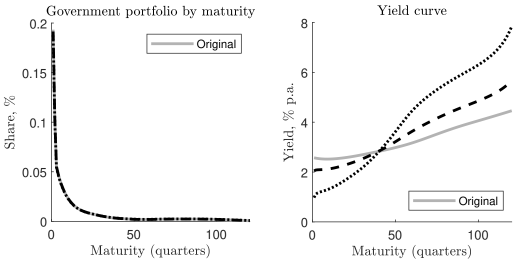

Figure: Government's bond issuance portfolio and yield curve

- 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

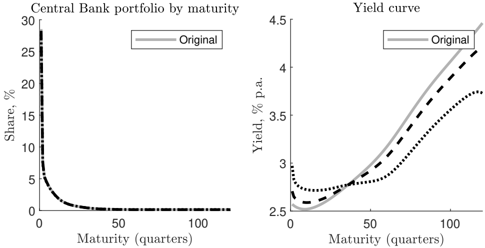

Figure: Central bank's bond demand portfolio and yield curve

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

Short-run analysis (Impulse-responses)

Again...

Big Findings (Conventional vs. Unconventional)

1. Unconventional monetary policy is very powerful in terms of stabilization in both normal and ZLB periods
2. As a drawback, the economy gets addicted to its power under ZLB regimes

Why?: long term yields↓ $\Longrightarrow$ downward pressure on short term yields↓ $\Longrightarrow$ ZLB duration↑ $\Longrightarrow$ more reliance on LSAPs

Welfare (similar to Coibion et al. (2012))

Trend inflation term

$$\mathbb{E}U_t - \bar{U}^F = \Omega_0 + \Omega_n \mathrm{Var}(\hat{n}_t) + \Omega_\pi \mathrm{Var}(\hat{\pi}_t) + \text{t.i.p} + \text{h.o.t}$$

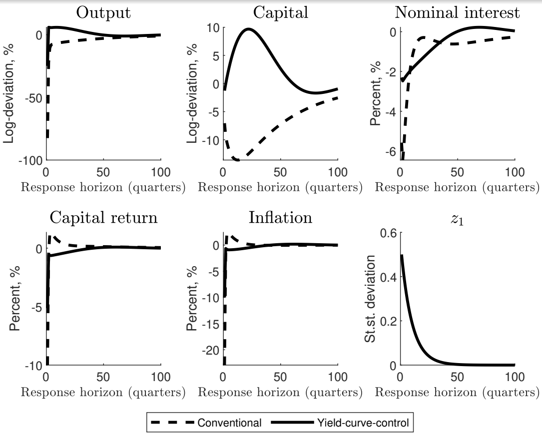

Figure: Impulse response to z_t^1 shock

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)

ZLB impulse response to z_t^1

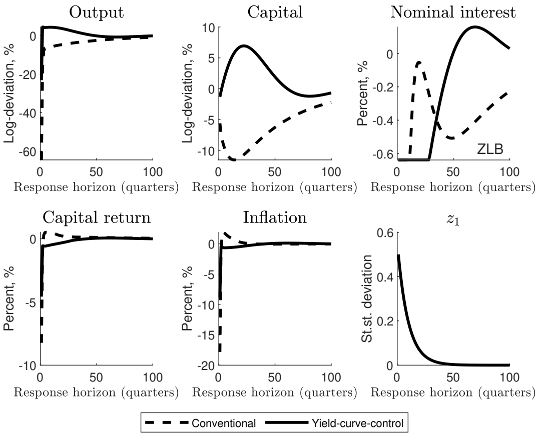

Figure: ZLB impulse response to z_t^1 shock

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

- But duration of ZLB episodes↑

ZLB $\Longrightarrow$ long-term rates↓ $\Longrightarrow$ ZLB possibility↑

ZLB IRF (z_t^K)

ZLB impulse response to an exogenous tax hike

Normal IRF (tax)

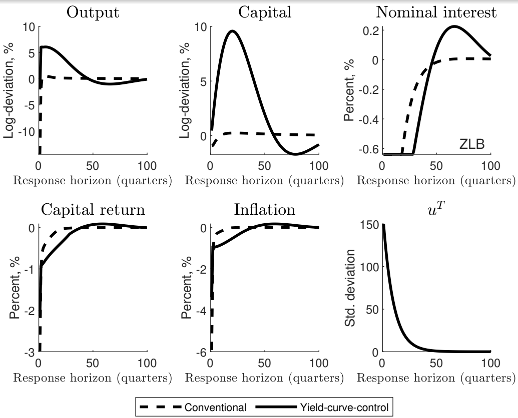

Figure: ZLB impulse response to ϵ_t^T shock

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

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

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

ζ_t^G ↑ $\frac{G_t}{Y_t}$ (Exogenous)

ζ_t^T ↑ $\frac{T_t}{Y_t}$ (Exogenous)

$\lambda_{t-1}^{G,f+1}$ ↑ (Exogenous)

- **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:

$$\log\left(\lambda_{t+h}^{H,f}\right) - \log\left(\lambda_{t+h}^{H,l}\right) = \alpha_h^{fl} + \kappa_{B,h} \cdot \left[yd_t^f - yd_t^l\right] + \mathbf{x}_t'\beta_h^{\mathbf{fl}} + \varepsilon_{t+h}^{fl}, \; h \geq 0 \,, \quad (2)$$

- 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 $yd_{t-1}^f - yd_{t-1}^l$ ($\perp$ with portfolio demand shocks, i.e., z_t^f, z_t^l)
- Control other variables (e.g., lagged $\log\left(\lambda_{t-1}^{H,f}\right) - \log\left(\lambda_{t-1}^{H,l}\right)$ for seriel correlation)

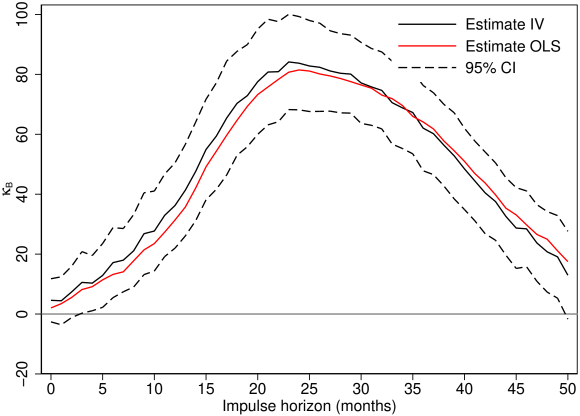

Figure: Impulse-Response to a shock in the yield spread, $yd_t^f - yd_t^l$. The figure presents the coefficient estimates for the bond portfolio elasticity, κ_B, in ((2)). The solid black line illustrates the estimate from the instrumental variables (IV) regression, with dashed lines indicating the 95% robust confidence intervals. The red line exhibits alternative OLS estimates. The sample period is from 2003m3 to 2019m3.

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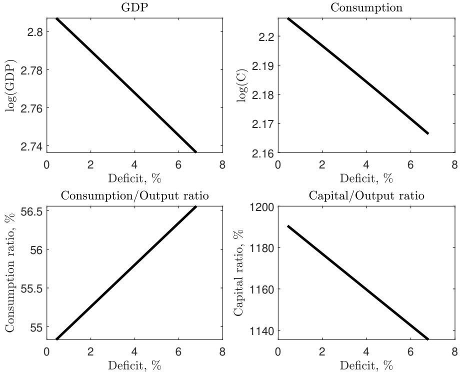

Figure: Variations in a deficit ratio $\zeta_t^G + \zeta^F - \zeta_t^T$

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

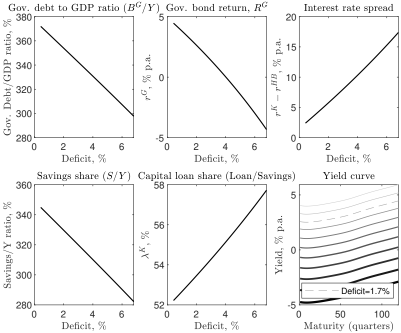

Figure: Variations in a deficit ratio $\zeta_t^G + \zeta^F - \zeta_t^T$

- A higher deficit ratio $\Rightarrow$ depressed economy (for $R^G\downarrow$)
  - An entire yield curve$\downarrow$

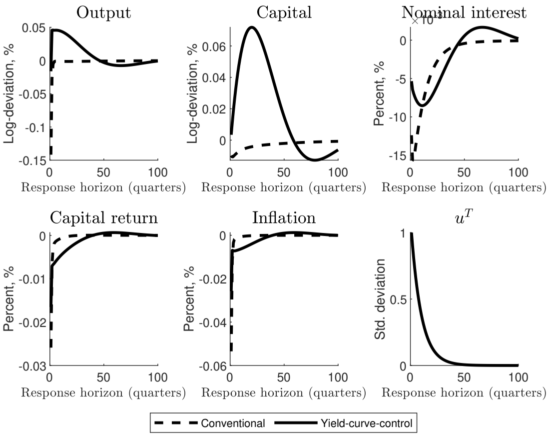

Figure: Impulse response to ϵ_t^T shock

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

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

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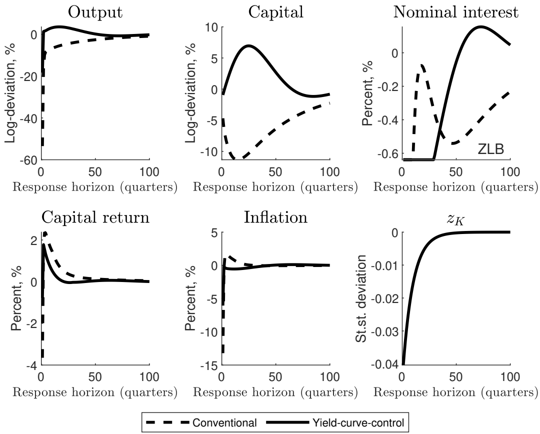

Figure: ZLB impulse response to z_t^K shock

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

- But duration of ZLB episodes↑

ZLB $\Longrightarrow$ long-term rates↓ $\Longrightarrow$ ZLB possibility↑

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