Optimal quantitative easing and tightening

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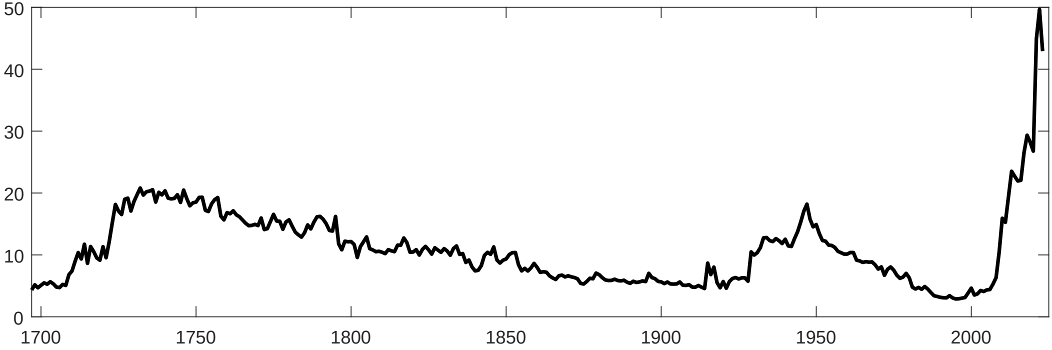
Motivation

Figure 1: Bank of England balance sheet as a percentage of nominal UK GDP, 1697-2023



- What is the optimal use of the balance sheet for monetary policy purposes?
- How should existing asset purchase programmes be unwound?

Literature

Portfolio balance channel & related financial frictions

- Tobin (1956, 1969), Tobin and Brainard (1963), Frankel (1985)
- Andrés, López-Salido, and Nelson (2004), Harrison (2011), Ellison and Tischbirek (2014), Chen, Cúrdia, and Ferrero (2012), Carlstrom, Fuerst, and Paustian (2017)

Optimal policy ...

- Harrison (2012), Darracq Pariès and Kühl (2016), Quint and Rabanal (2017), Sims, Wu, and Zhang (2020), Bonciani and Oh (2021), Mau (2022)

... including quantitative tightening

- Karadi and Nakov (2021), Benigno and Benigno (2022)

Method and key findings

- Embed portfolio balance friction in workhorse New Keynesian model
  - Short-term and long-term government bonds are imperfect substitutes
  - QE reduces long rate and increases aggregate demand (& vice versa for QT)
- Optimal time-consistent policy
  - Two instruments: policy rate and balance sheet (i.e., QE & QT)
  - Policy minimises welfare-based loss, subject to bounds on policy instruments
- Optimal policy
  - QE purchase pace more rapid than unwind (i.e., QT)
  - Policy rate is primary instrument away from the lower bound
  - QT typically starts **before** policy rate lifts off from lower bound
- Policymaker with ‘flexible inflation targeting’ mandate can achieve similar welfare losses when QT starts after liftoff (if QT pace is calibrated appropriately)

Model overview

- Workhorse New Keynesian model (Woodford, 2003; Galí, 2008)
  - Representative household maximises lifetime utility from consumption and leisure
  - Monopolistically competitive firms with Calvo (1983) price setting
- Financial intermediaries $\rightarrow$ portfolio balance channel
  - Invest household savings in short-term and long-term government bonds
  - Face costs of
    - Deviating from desired portfolio mix: 'maintenance cost'
    - Changing portfolio mix: 'adjustment cost'
  - Similar in spirit to Cúrdia and Woodford (2016) approach
    $\Rightarrow$ "reduced-form intermediation technology" with a "minimum of structure"
- Why focus on portfolio balance channel?
  - Many (UK & US) monetary policymakers highlighted it (Joyce, McLaren, and Young, 2012)
  - Frictions that give balance sheet policies traction should guide optimal use

Financial intermediary

- Maximizes real profits discounted by marginal utility (Λ)

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \frac{\Omega_t^I}{P_t}$$

- Subject to a balance sheet constraint:

$$S_t \geqslant B_t^I + D_t^I + Z_t^I$$

- Nominal profit is:

$$\Omega_t^I = S_t - B_t^I - D_t^I - Z_t^I + R_{t-1} Z_{t-1}^I + R_{t-1}^B B_{t-1}^I + R_t^D D_{t-1}^I$$
$$- R_{t-1}^S S_{t-1} - \left(z^I + b^I + d^I\right) P_t \mathcal{M}\left(\delta \rho_t^I\right) - \left(z^I + b^I + d^I\right) P_t \mathcal{A}\left(\rho_t^I - \rho_{t-1}^I\right)$$

  where $\rho_t^I \equiv \frac{Z_t^I + B_t^I}{D_t^I}$; Z = reserves; B = short-term debt; D = long-term debt

- 'Maintenance' and 'adjustment' costs satisfy $\mathcal{M}(1) = \mathcal{M}'(1) = \mathcal{A}(0) = \mathcal{A}'(0) = 0$ and $\mathcal{M}''(1) = \tilde{\nu}$ and $\mathcal{A}''(1) = \tilde{\xi}$

Model

$$\hat{\pi}_t = \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa \hat{x}_t + u_t \tag{1}$$

$$\hat{x}_t = \mathbb{E}_t \hat{x}_{t+1} - \sigma \left[\widetilde{R}_t - \mathbb{E}_t \hat{\pi}_{t+1} - r_t^* \right] \tag{2}$$

- Phillips curve (1) relates inflation ($\hat{\pi}$) to output gap ($\hat{x}$) & cost-push shock (u)
- IS curve (2) depends on **'shadow rate'** (Wu and Zhang, 2019), $\widetilde{R}$

Model

$$\hat{\pi}_t = \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa \hat{x}_t + u_t \tag{1}$$

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- Phillips curve (1) relates inflation ($\hat{\pi}$) to output gap ($\hat{x}$) & cost-push shock (u)
- IS curve (2) depends on **'shadow rate'** (Wu and Zhang, 2019), $\widetilde{R}$

$$\widetilde{R}_t = \hat{R}_t - \tilde{q}_t \tag{3}$$

$$\tilde{q}_t = [\nu + (1 + \beta)\,\xi]\, q_t - \xi q_{t-1} - \beta \xi \mathbb{E}_t q_{t+1} \tag{4}$$

$\hat{R}$ = policy rate (interest rate on reserves)
$\tilde{q}$ = 'effective balance sheet' (accounting for dynamics)
q = central bank balance sheet (share of long-term government debt held by central bank)

$\Rightarrow$ strong substitutability of balance sheet and short-term policy rate

- Balance sheet effects depend on portfolio 'maintenance' (ν) & 'adjustment' (ξ) costs

Welfare-based loss function & optimal policy

$$\mathcal{L}_t = \mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left(\omega_x \hat{x}_\tau^2 + \omega_\pi \hat{\pi}_\tau^2 + \omega_q q_\tau^2 + \omega_{\Delta q} \left(q_\tau - q_{\tau-1} \right)^2 \right)$$

- Welfare-based loss function reflects frictions in model
  - First two terms from price stickiness (standard from workhorse New Keynesian model)
  - Third and fourth terms from portfolio balance friction
- Policy mix features both symmetries and asymmetries
  - Policy rate and balance sheet are perfect substitutes in setting shadow rate ($\widetilde{R}$)
  - But only balance sheet enters loss function $\Rightarrow$ asymmetry in instrument use
- Key features of optimal balance sheet policy
  - Accounts for portfolio distortions associated with balance sheet policies
  - Equates marginal cost of balance sheet use with marginal benefit of macro stabilisation

The optimal policy problem

- The monetary policymaker sets policy rate ($\hat{R}$) and size of balance sheet (q)
- Minimise loss $\mathcal{L}$ subject to constraints on policy instruments
  - $\hat{R} \geqslant \ln \beta$ (zero lower bound)
  - $q \geqslant \underline{q} = 0$ (central bank cannot issue long bonds)
  - $q \leqslant \bar{q} \leqslant 1$ (cannot purchase more than entire stock)
- Policymaker sets optimal time-consistent policy
- Why not commitment?
  - GFC $\rightarrow$ QE, not ('Odyssean') forward guidance (Bernanke, 2022)
    (Nakata (2015) $\Rightarrow$ policymakers unsure of their ability to credibly commit?)
  - Welfare gains from balance sheet policy under commitment are very small

Optimal balance sheet policy

- First order condition for balance sheet can be written as

$$\Theta\tilde{q}_t = \left[\boldsymbol{D}_t^X + \sigma\boldsymbol{D}_t^\Pi + \sigma\gamma - \beta\sigma\xi\boldsymbol{D}_t^Q\right]\lambda_t^x - \beta\sigma\xi\mathbb{E}_t\lambda_{t+1}^x - \beta\boldsymbol{D}_t^\Pi\omega_\pi\hat{\pi}_t + \lambda_t^{\bar{q}} + \lambda_t^{\underline{q}}$$

  where $\boldsymbol{D}_t^Z \equiv \dfrac{\partial\mathbb{E}_t\boldsymbol{Z}_{t+1}}{\partial q_t}$ for $Z = \{\Pi, X, Q\}$

  and $\lambda^x, \lambda^{\bar{q}}, \lambda^{\underline{q}}$ are Lagrange multipliers on IS curve and balance sheet constraints

- Insights from FOC and special cases:
  - Optimal policy depends on $\tilde{q}$ rather than q
  - Need ZLB to bind ($\lambda^x > 0$) for $\widetilde{q}_t \neq 0$
  - $\widetilde{q}_t < 0$ when 'close to' the ZLB ($\lambda^x \approx 0$; $\mathbb{E}_t\lambda_{t+1}^x > 0$) $\Rightarrow$ start QT before liftoff
  - In absence of ZLB, first order condition implies $\widetilde{q}_t = 0$: $\widetilde{q}_t \approx 0$ when far from ZLB

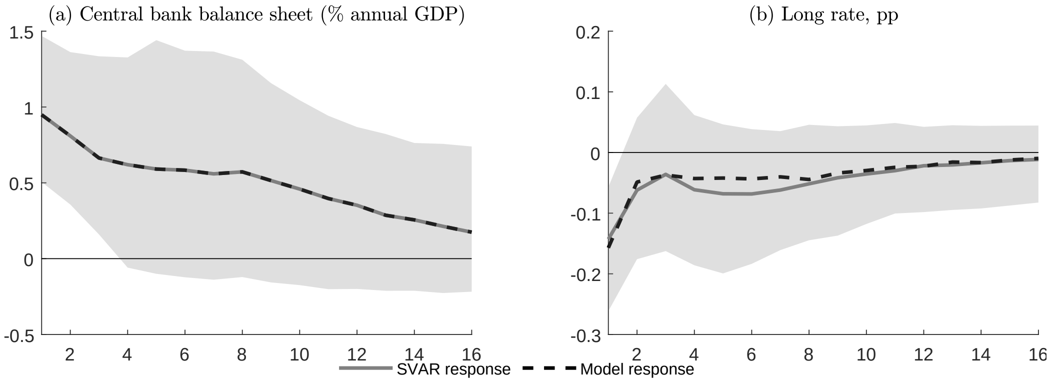
Parameter values

	Description	Value		Description	Value
σ	Intertemporal substitution elasticity	1	χ	Long bond (non)-redemption probability	0.982
κ	Slope of Phillips curve	0.024	δ	Ratio of long-term to short-term bonds	1.34
β	Discount factor	0.9925	Θ	Debt stock/output ratio	0.81
ψ	Inverse Frisch elasticity	5	$\nu \times 100$	Adjustment cost (portfolio mix)	0.38
α	Capital share in production	0.25	$\xi \times 100$	Adjustment cost (change in portfolio mix)	5.97
η	Elasticity of substitution	9	$\underline{q}$	Lower bound on balance sheet	0
θ	Calvo probability	0.9	$\bar{q}$	Upper bound on balance sheet	0.7
ρ_r	Autocorrelation, natural rate	0.875			
$100\sigma_r$	Standard deviation, natural rate	0.20			
ρ_u	Autocorrelation, cost push shock	0			
$100\sigma_u$	Standard deviation, cost push shock	0.15			

- Workhorse New Keynesian parameters
  - $\beta \Rightarrow$ SS nominal rate = 3% pa (Del Negro, Giannone, Giannoni, and Tambalotti, 2019)
  - $\sigma, \eta, \alpha, \psi$ from Galí (2008), $\theta \Rightarrow \kappa = 0.024$ (Eggertsson and Woodford, 2003)
- Government debt parameters calibrated to UK data
  - $\chi \Leftrightarrow$ long-term debt duration is 10 years; δ and Θ from pre-GFC UK data (DMO)
  - $\bar{q}$ based on BoE purchase limits (Logan and Blindseil, 2019); $\underline{q} = 0$

Parameter values

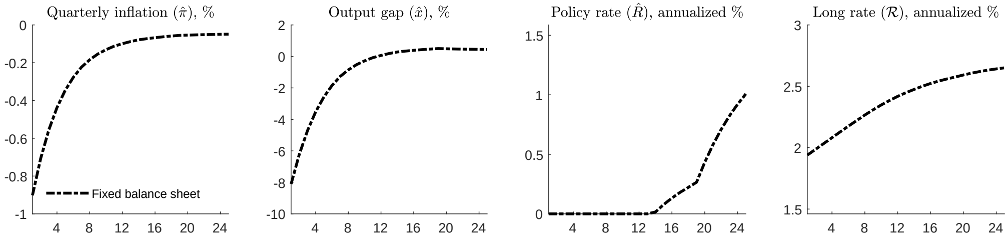
Impulse response matching



- ν, ξ chosen to match SVAR response to QE shock (Weale and Wieladek, 2016)
- Initial 'kink' in long rate response $\Leftrightarrow$ ξ is 'large'

QE and QT in action

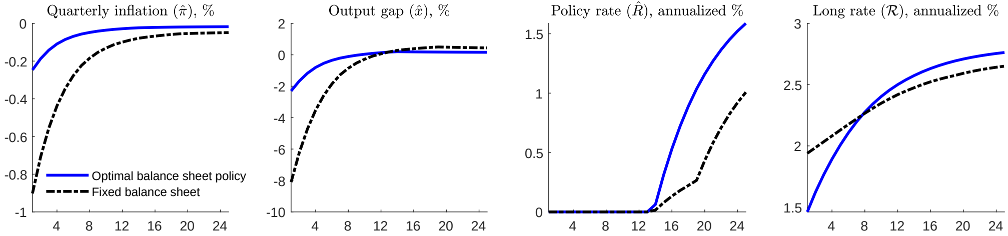
Simulated response to large reduction in r^*



- Without QE there is a large recession & ZLB binds for over three years

QE and QT in action

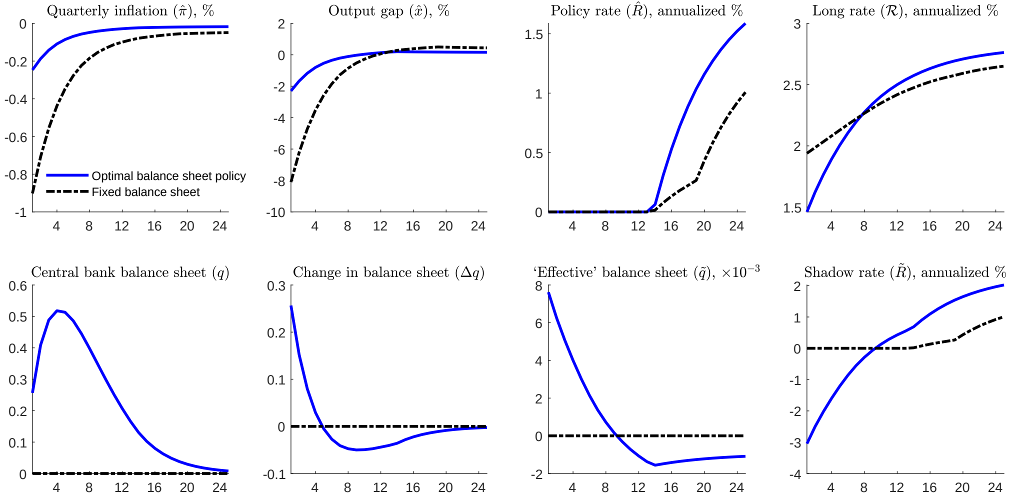
Simulated response to large reduction in r^*



- QE mitigates recession by reducing long rate in near term

QE and QT in action

Simulated response to large reduction in r^*



- Large QE response with initial asset purchases faster than subsequent unwind

Model vs real-world policy strategies

MPC / FOMC behaviour	Optimal policy in model
QT more gradual than QE	✓
Policy rate is 'active instrument' away from ELB	✓
QT starts after policy rate lifts off from ELB	✗

- Several factors that affect sequencing choice are abstracted from
  - If total debt issuance increases, q can fall without shrinking balance sheet
  - High uncertainty around effects of QE and QT
  - State contingency of effects of balance sheet policies
- In the model, optimal QT sequencing is driven by balance sheet costs in loss function

Model vs real-world policy strategies

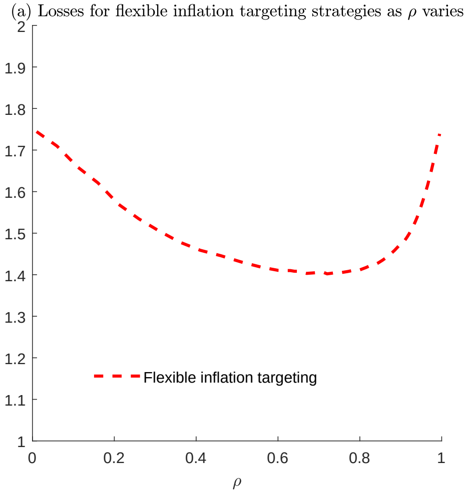
MPC / FOMC behaviour	Optimal policy in model
QT more gradual than QE	✓
Policy rate is ‘active instrument’ away from ELB	✓
QT starts after policy rate lifts off from ELB	✗

- Suppose instead central bank minimises ‘flexible inflation targeting’ loss function

$$\mathcal{L}_t^{FIT} = \mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left(\omega_x \hat{x}_\tau^2 + \omega_\pi \hat{\pi}_\tau^2 \right)$$

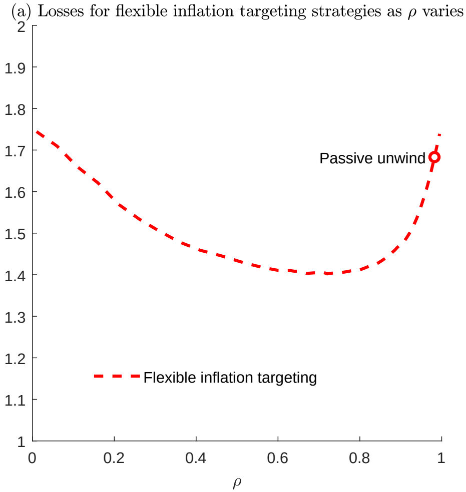
- Policy behaviour
  - Shadow rate delivers standard New Keynesian targeting criterion ($\omega_x \hat{x}_t + \kappa \omega_\pi \hat{\pi}_t = 0$)
  - QT starts **after** liftoff from ZLB
  - Simple ‘QT rule’ $q_t = \rho q_{t-1}$ when away from ZLB

Flexible inflation targeting and QT



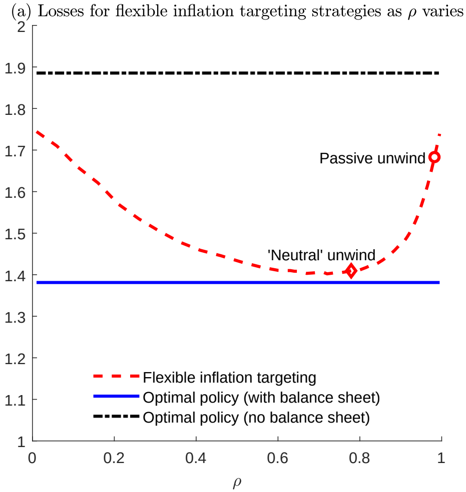
- Slower QT ⇔ **larger** ρ

Flexible inflation targeting and QT



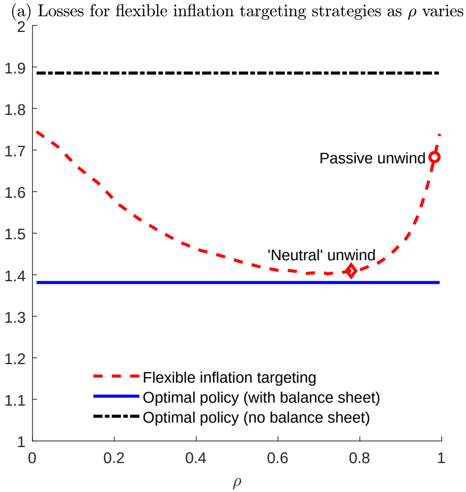
- Passive unwind $\Rightarrow$ substantial welfare costs

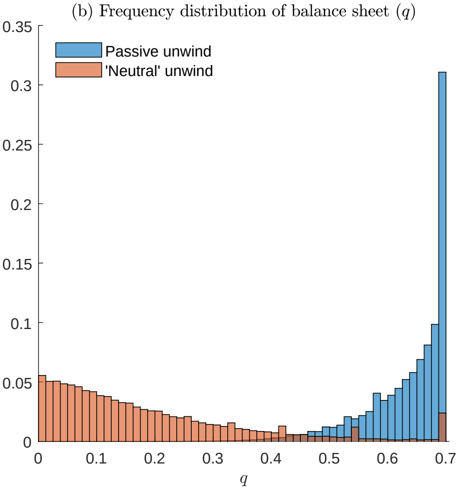
Flexible inflation targeting and QT



- ‘Neutral’ unwind ($\widetilde{q}_t = 0$ away from the ZLB) close to optimal time-consistent policy
- Very rapid unwind $\Rightarrow$ greater balance sheet variability and higher losses

Flexible inflation targeting and QT





- Passive unwind leads to ‘balance sheet ratchet’
- Severity depends on upper bound on QE (here, $\bar{q} = 0.7$)

Concluding remarks

- Embed simple portfolio friction in workhorse New Keynesian model
  - Captures 'portfolio balance channel'
  - Match empirical evidence on effects of QE on long rates
- Study optimal time-consistent policy
- Key findings
  - Optimal deployment of balance sheet delivers substantial welfare gains
  - Optimal policy implies faster asset purchases and slower unwind
  - Optimal policy suggests starting QT **before** liftoff from lower bound
  - 'Flexible inflation targeting' can deliver similar welfare if QT is calibrated appropriately

ADDITIONAL MATERIAL

Further details

- Model
  - Government bonds/debt
  - Fiscal policy
  - Portfolio balance channel & Financial intermediaries
- Optimal policy
  - Optimal policy problem
  - Lagrangean
  - First order condition for balance sheet
  - Special cases
- Results
  - Policy functions
  - Distribution of the balance sheet
  - Welfare analysis
  - Flexible inflation targeting with alternative QT strategies

Government debt ◂ Back

- Short-term nominal bonds (B) are standard
  - One unit purchased at t pays sure nominal return R_t at $t+1$

- Long-term nominal debt (D)
  - Zero coupon bond, matures at par value 1
  - Bond matures with probability χ each period
  - Implies similar pricing equations to Woodford (2001) bond
  - Facilitates analysis of 'passive unwind' of QE

Fiscal policy and QE Back

- Simple tax and spending assumption
  - No government spending
  - Lump sum taxes adjust to stabilise debt stocks
- Debt issuance optimal with respect to portfolio frictions
  - Short-term and long-term debt held fixed in real terms
  - Ratio equal to intermediaries' efficient ratio
- Monetary/fiscal interactions
  - 'Passive' fiscal policy (Leeper, 1991)
  - 'Passive' central bank remittance policy (Benigno and Nisticò, 2020)
  - $\Rightarrow$ neutrality w.r.t. central bank balance sheet
- Assumptions mirror key aspects of UK approach to QE
  - Indemnification of APF $\Rightarrow$ fiscal support (Del Negro and Sims, 2015)
  - Chancellor letter to DMO re issuance stategy

Fiscal policy and QE Back

- Nominal government budget constraint:

$$B_t + V_t \widetilde{D}_t = R^B_{t-1} B_{t-1} + (1 - \chi + \chi V_t)\, \widetilde{D}_{t-1} - \Omega^C_t - P_t \tau_t$$

B = short-term debt (T-bills)

$\widetilde{D}$ = long-term debt ($D \equiv V \times \widetilde{D}$ is market value of debt)

Ω^C = remittances from(/to) central bank

τ = net tax/transfer payments from/to households

Fiscal policy and QE ◂ Back

Central bank

- Central bank budget constraint:

$$\Omega_t^C = Z_t - R_{t-1}^Z Z_{t-1} - \left(V_t \widetilde{D}_t^C - (1 - \chi + \chi V_t)\, \widetilde{D}_{t-1}^C \right)$$

- Central bank balance sheet constraint:

$$V_t \widetilde{D}_t^C = Z_t$$

- Combining:

$$\Omega_t^C = \underbrace{\frac{1 - \chi + \chi V_t}{V_{t-1}}}_{\equiv R_{1,t}^D} V_{t-1} \widetilde{D}_{t-1}^C - R_{t-1}^Z Z_{t-1} = \left[R_{1,t}^D - R_{t-1}^Z \right] Z_{t-1}$$

$\Rightarrow$ remittances are determined by portfolio revaluation effects

The portfolio balance channel ◂ Back

- Bernanke (2010) on how QE works:

  I see the evidence as most favorable to the view that such purchases work primarily through the so-called portfolio balance channel, which holds that once short-term interest rates have reached zero, the Federal Reserve's purchases of longer-term securities affect financial conditions by changing the quantity and mix of financial assets held by the public.

  $\Rightarrow$ relative quantities of assets affect relative prices

- A broad church: many mechanisms could give rise to such an effect
  - Asset pricing kernels that depend on average return on wealth: King (2015)
  - Preferred habitats: Vayanos and Vila (2021), Carboni and Ellison (2022)
  - Imperfectly substitutable assets: Tobin (1956, 1969), Tobin and Brainard (1963), Frankel (1985), Andrés et al. (2004), Ellison and Tischbirek (2014), Harrison (2012), Gertler and Karadi (2011), Chen et al. (2012), Carlstrom et al. (2017), Sims et al. (2020), Sims and Wu (2021), Bonciani and Oh (2021)
- Deliberately abstract from other potential QE channels
  - Liquidity effects: Aksoy and Basso (2014) & Bank lending channel: Rodnyansky and Darmouni (2017)
  - Signalling: Bhattarai, Eggertsson, and Gafarov (2015, 2022)
  - Monetary/fiscal interactions: Reis (2017), Benigno and Nisticò (2020), Airaudo (2022)

Financial intermediary ◂ Back

- Maximizes real profits discounted by marginal utility (Λ)

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \frac{\Omega_t^I}{P_t}$$

- Subject to a balance sheet constraint:

$$S_t \geqslant B_t^I + D_t^I + Z_t^I$$

- Nominal profit is:

$$\begin{aligned}\Omega_t^I = {} & S_t - B_t^I - D_t^I - Z_t^I + R_{t-1} Z_{t-1}^I + R_{t-1}^B B_{t-1}^I + R_t^D D_{t-1}^I \\ & - R_{t-1}^S S_{t-1} - \left(z^I + b^I + d^I\right) P_t \mathcal{M}\left(\delta \rho_t^I\right) \\ & - \left(z^I + b^I + d^I\right) P_t \mathcal{A}\left(\rho_t^I - \rho_{t-1}^I\right)\end{aligned}$$

where $\rho_t^I \equiv \frac{Z_t^I + B_t^I}{D_t^I}$

The optimal policy problem ◂ Back

- The monetary policymaker sets policy rate ($\hat{R}$) and size of balance sheet (q)
- Minimise loss $\mathcal{L}$ subject to constraints on policy instruments
  - $\hat{R} \geqslant \ln \beta$ (zero lower bound)
  - $q \geqslant 0$ (central bank cannot issue long bonds)
  - $q \leqslant \bar{q} \leqslant 1$ (cannot purchase more than entire stock)
- Policymaker sets optimal time consistent policy
  - Cannot commit to future policy actions
- Why not commitment?
  - GFC $\rightarrow$ QE, not ('Odyssean') forward guidance (Bernanke, 2022)
  - Welfare gains from balance sheet policy under commitment are very small
- Solution method
  - Projection methods to account for instrument bounds

The optimal policy problem Back

$$\min_{\{\hat{\pi}_t,\hat{x}_t,\hat{R}_t,q_t\}} \mathcal{L} = \frac{1}{2}\sum_{t=0}^{\infty}\beta^t\left(\ \omega_x\hat{x}_t^2+\omega_\pi\hat{\pi}_t^2+\omega_q q_t^2+\omega_{\Delta q}\left(q_t-q_{t-1}\right)^2\ \right)$$

subject to:

$$\hat{x}_t = \mathbb{E}_t\hat{x}_{t+1}-\sigma\left[\ \hat{R}_t-\mathbb{E}_t\hat{\pi}_{t+1}-\gamma q_t+\xi q_{t-1}+\beta\xi\mathbb{E}_t q_{t+1}-r_t^*\ \right]$$

$$\hat{\pi}_t = \beta\mathbb{E}_t\hat{\pi}_{t+1}+\kappa\hat{x}_t+u_t$$

$$\hat{R}_t \geqslant \ln\beta$$

$$q_t \geqslant 0$$

$$q_t \leqslant \bar{q}$$

The Lagrangean ◂ Back

$$\begin{aligned}\min_{\{\hat{\pi}_t,\hat{x}_t,\hat{R}_t,q_t\}} & \frac{\omega_x}{2}\hat{x}_t^2 + \frac{\omega_\pi}{2}\hat{\pi}_t^2 + \frac{\omega_q}{2}q_t^2 + \frac{\omega_{\Delta q}}{2}\left(q_t - q_{t-1}\right)^2 + \beta\mathbb{E}_t\mathcal{L}_{t+1}\left(q_t\right) \\ & - \lambda_t^\pi\left(\hat{\pi}_t - \kappa\hat{x}_t - \beta\mathbb{E}_t\mathbf{\Pi}\left(q_t\right) - u_t\right) \\ & - \lambda_t^x\left(\hat{x}_t - \mathbb{E}_t\boldsymbol{X}\left(q_t\right) + \sigma\left(\begin{array}{l}\hat{R}_t - \mathbb{E}_t\mathbf{\Pi}\left(q_t\right) - \gamma q_t \\ +\xi q_{t-1} + \beta\xi\mathbb{E}_t\boldsymbol{Q}\left(q_t\right) - r_t^*\end{array}\right)\right) \\ & - \lambda_t^R\left(\hat{R}_t - \ln\beta\right) - \lambda_t^{\bar{q}}\left(q_t - \bar{q}\right) - \lambda_t^{\underline{q}}\left(q_t - \underline{q}\right)\end{aligned}$$

- Policymaker accounts for effects of q_t via $\boldsymbol{X}$, $\mathbf{\Pi}$ and $\boldsymbol{Q}$
- Policymaker takes (functions) $\boldsymbol{X}$, $\mathbf{\Pi}$ and $\boldsymbol{Q}$ as given
- Solution is fixed point (solved via policy function iteration)
  - Decisions satisfy first order conditions
  - Decisions are consistent with policy functions

First order condition for balance sheet Back

First order condition for QE can be written as

$$
\begin{aligned}
0 = \Theta \tilde{q}_t + \beta \sigma \xi \mathbb{E}_t \lambda^x_{t+1} + \beta \boldsymbol{D}^{\Pi}_t \omega_\pi \hat{\pi}_t \\
- \left[\boldsymbol{D}^X_t + \sigma \boldsymbol{D}^{\Pi}_t + \sigma \gamma - \beta \sigma \xi \boldsymbol{D}^Q_t \right] \lambda^x_t - \lambda^{\bar{q}}_t - \lambda^{\underline{q}}_t
\end{aligned}
$$

where

$$
\boldsymbol{D}^Z_t \equiv \frac{\partial \mathbb{E}_t \boldsymbol{Z}_{t+1}}{\partial q_t}
$$

for $Z = \{\Pi, X, Q\}$ and $\lambda^x, \lambda^\pi, \lambda^{\bar{q}}, \lambda^{\underline{q}}$ are Lagrange multipliers on IS curve, Phillips curve and QE constraints

$\Rightarrow$ optimal deployment of QE depends on $\tilde{q}$ rather than q

Optimal balance sheet: some special cases Back

1. No portfolio 'adjustment' costs ($\xi = 0$)

$$\underbrace{\Theta\delta^{-1}q_t}_{\text{Marginal cost of using QE}} = \underbrace{-\sigma\left(\omega_x\hat{x}_t + \kappa\omega_\pi\hat{\pi}_t\right)}_{\text{Marginal cost of deviating from NK optimality condition}}$$

2. If bounds on QE never bind, $\boldsymbol{D}_t^X = \boldsymbol{D}_t^\Pi = 0$, $\boldsymbol{D}_t^Q = \boldsymbol{D}^Q$:

$$\Theta\tilde{q}_t = -\beta\sigma\xi\mathbb{E}_t\lambda_{t+1}^x + \left[\sigma\gamma - \beta\sigma\xi\boldsymbol{D}^Q\right]\lambda_t^x$$

$\Rightarrow$ require ZLB ($\lambda^x > 0$) for $\widetilde{q}_t \neq 0$

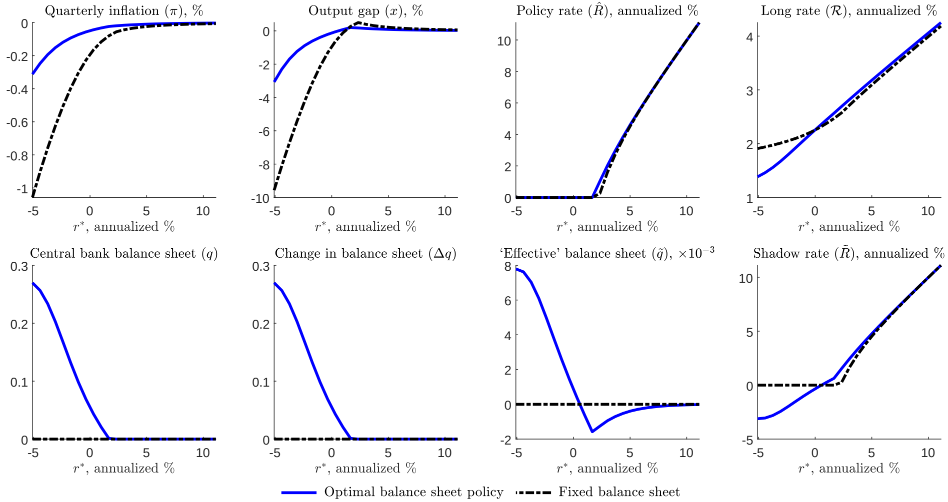
$\Rightarrow$ $\widetilde{q}_t < 0$ when ZLB 'weakly binds' ($\lambda^x \approx 0$; $\mathbb{E}_t\lambda_{t+1}^x > 0$) $\Rightarrow$ start QT before liftoff

3. In absence of ZLB, first order condition implies $\widetilde{q}_t = 0$

$\Rightarrow$ when far away from ZLB $\widetilde{q}_t \approx 0$

Policy functions ◂ Back

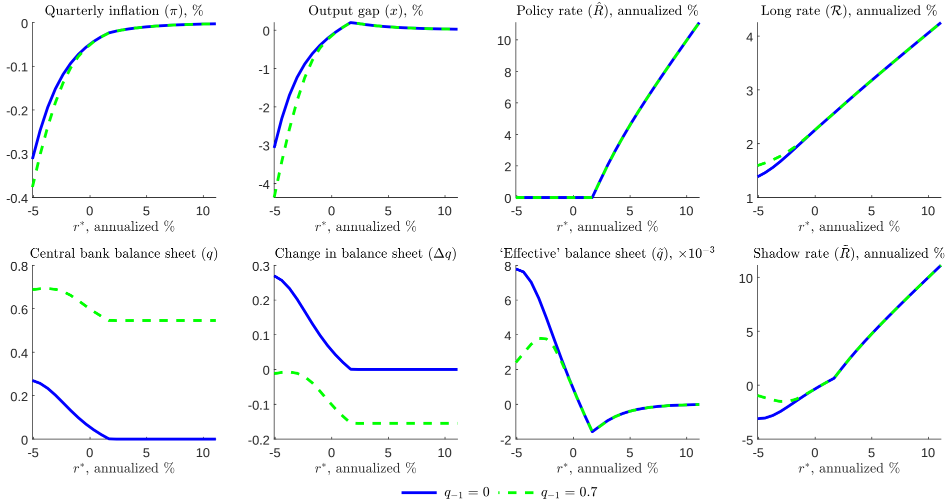
Conditional on $u = 0$; $q_{-1} = 0$ & case of no balance sheet policy



- QE mitigates effects of low r^*: without QE, ZLB very costly given r^* persistence

Policy functions ◂ Back

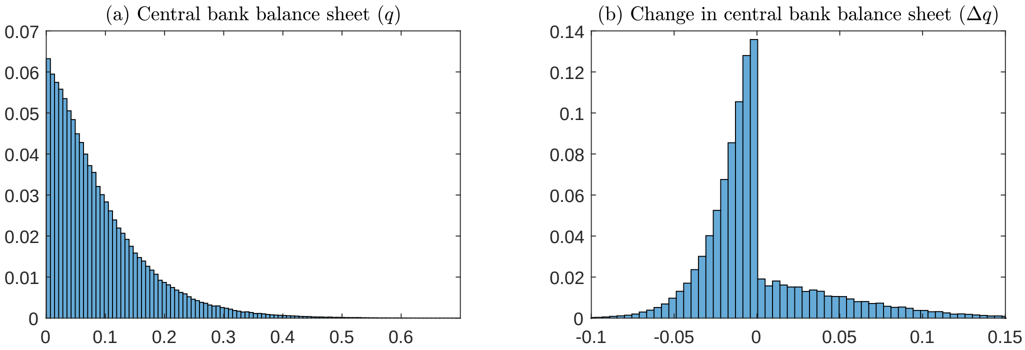
Conditional on $u = 0$; $q_{-1} = 0$ & $q_{-1} = \bar{q}$



- Upper bound on q binds for very low r^*, but away from $\bar{q}$ achieve same shadow rate

Distribution of balance sheet
Back

q distribution mostly $< \bar{q}$; Δq distribution skewed to the right



- Upper bound on q almost never binding
- Lower bound on q does not affect stance (can set higher $\hat{R}$)
- Optimal deployment of balance sheet implies QE faster than QT

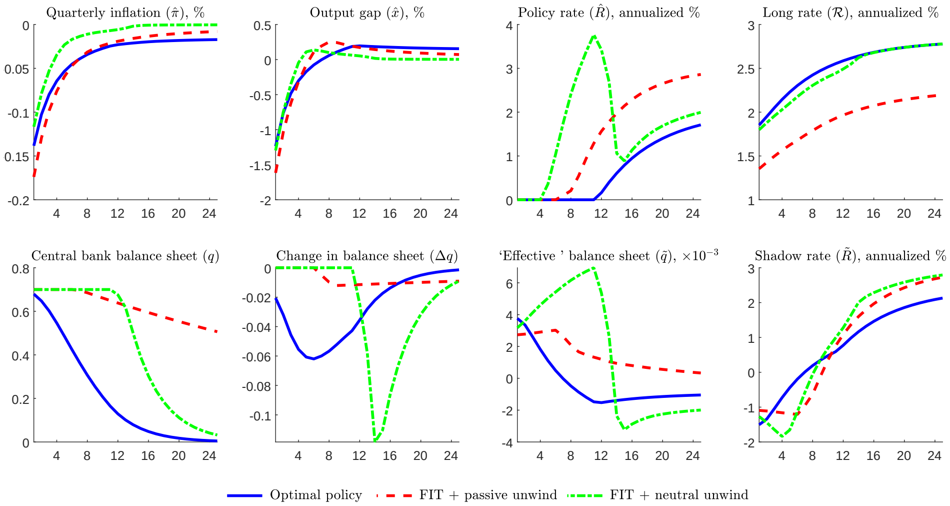
Results

Back

Welfare (computed from stochastic simulation of 500,000 periods)

	Time consistent		Commitment	
	$\hat{R}$ and q	$\hat{R}$ only	$\hat{R}$ and q	$\hat{R}$ only
Quarterly inflation, %	-0.02	-0.07	0.00	0.00
Output gap, %	-0.01	-0.02	-0.00	-0.00
Policy rate, annualized %	3.06	2.75	3.02	3.02
Long-term rate, annualized %	2.82	2.75	3.01	3.01
QE (q)	0.09	0.00	0.01	0.00
Loss ($\times$100)	0.60	0.82	0.43	0.44
Relative loss	1.38	1.89	1.00	1.00
ZLB frequency, %	38	40	12	12

Flexible inflation targeting with alternative QT strategies ◂ Back



- 'Neutral unind' requires sharp reduction in policy rate when QT begins

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