Optimal quantitative easing and tightening

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Views are those of the author and do not reflect views of the Bank of England or any of its policy committees.
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)

Optimal policy . . .


. . . 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 (and 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 → 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
    ⇒ “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 ($\Lambda$)
  \[ \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \frac{\Omega^I_t}{P_t} \]

- Subject to a balance sheet constraint:
  \[ S_t \geq B_t^I + D_t^I + Z_t^I \]

- Nominal profit is:
  \[
  \Omega_t^I = S_t - B_t^I - D_t^I - Z_t^I + R_{t-1} Z_{t-1}^I + R_{t-1}^B B_{t-1}^I + R_{t-1}^D D_{t-1}^I \\
  - R_{t-1}^S S_{t-1} - (z^I + b^I + d^I) P_t M (\delta \rho^I_t) - (z^I + b^I + d^I) P_t A (\rho^I_t - \rho^I_{t-1})
  \]
  where $\rho_t^I \equiv \frac{Z_t^I + B_t^I}{D_t^I}$; $Z = \text{reserves; } B = \text{short-term debt; } D = \text{long-term debt}$

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

\[ \hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa \hat{x}_t + u_t \quad (1) \]

\[ \hat{x}_t = E_t \hat{x}_{t+1} - \sigma \left[ \tilde{R}_t - E_t \hat{\pi}_{t+1} - r^*_t \right] \quad (2) \]

- 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), \( \tilde{R} \)
Model

\[ \hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa \hat{x}_t + u_t \]  
(1)

\[ \hat{x}_t = E_t \hat{x}_{t+1} - \sigma \left[ \tilde{R}_t - E_t \hat{\pi}_{t+1} - r^*_t \right] \]  
(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), \( \tilde{R} \)

\[ \tilde{R}_t = \hat{R}_t - \tilde{q}_t \]  
(3)

\[ \tilde{q}_t = [\nu + (1 + \beta) \xi] q_t - \xi q_{t-1} - \beta \xi E_t q_{t+1} \]  
(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)

⇒ strong substitutability of balance sheet and short-term policy rate
- Balance sheet effects depend on portfolio ‘maintenance’ (\( \nu \)) & ‘adjustment’ (\( \xi \)) costs
Welfare-based loss function & optimal policy

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

- 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 (\( \tilde{R} \))
  - 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
  - $\hat{R} \geq \ln \beta$ (zero lower bound)
  - $q \geq q = 0$ (central bank cannot issue long bonds)
  - $q \leq \bar{q} \leq 1$ (cannot purchase more than entire stock)

- Policymaker sets optimal time-consistent policy

- Why not commitment?
  - GFC → QE, not (‘Odyssean’) forward guidance (Bernanke, 2022)
    (Nakata (2015) ⇒ 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

\[ \Theta \tilde{q}_t = \left[ D_t^X + \sigma D_t^\Pi + \sigma \gamma - \beta \sigma \xi D_t^Q \right] \lambda_t^x - \beta \sigma \xi E_t \lambda_{t+1}^x - \beta D_t^\Pi \omega \pi \tilde{\alpha}_t + \lambda_t^{\tilde{q}} + \lambda_t^q \]

where \( D_t^Z \equiv \frac{\partial E_t Z_{t+1}}{\partial q_t} \) for \( Z = \{ \Pi, X, Q \} \)

and \( \lambda^x, \lambda^{\tilde{q}}, \lambda^q \) 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 \( \tilde{q}_t \neq 0 \)
- \( \tilde{q}_t < 0 \) when ‘close to’ the ZLB \( (\lambda^x \approx 0; E_t \lambda_{t+1}^x > 0) \) ⇒ start QT before liftoff
- In absence of ZLB, first order condition implies \( \tilde{q}_t = 0: \tilde{q}_t \approx 0 \) when far from ZLB
## Parameter values

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$ Intertemporal substitution elasticity</td>
<td>1</td>
</tr>
<tr>
<td>$\kappa$ Slope of Phillips curve</td>
<td>0.024</td>
</tr>
<tr>
<td>$\beta$ Discount factor</td>
<td>0.9925</td>
</tr>
<tr>
<td>$\psi$ Inverse Frisch elasticity</td>
<td>5</td>
</tr>
<tr>
<td>$\alpha$ Capital share in production</td>
<td>0.25</td>
</tr>
<tr>
<td>$\eta$ Elasticity of substitution</td>
<td>9</td>
</tr>
<tr>
<td>$\theta$ Calvo probability</td>
<td>0.9</td>
</tr>
<tr>
<td>$\rho_r$ Autocorrelation, natural rate</td>
<td>0.875</td>
</tr>
<tr>
<td>$100\sigma_r$ Standard deviation, natural rate</td>
<td>0.20</td>
</tr>
<tr>
<td>$\rho_u$ Autocorrelation, cost push shock</td>
<td>0</td>
</tr>
<tr>
<td>$100\sigma_u$ Standard deviation, cost push shock</td>
<td>0.15</td>
</tr>
</tbody>
</table>

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</tr>
</thead>
<tbody>
<tr>
<td>$\chi$ Long bond (non)-redemption probability</td>
<td>0.982</td>
</tr>
<tr>
<td>$\delta$ Ratio of long-term to short-term bonds</td>
<td>1.34</td>
</tr>
<tr>
<td>$\Theta$ Debt stock/output ratio</td>
<td>0.81</td>
</tr>
<tr>
<td>$\nu \times 100$ Adjustment cost (portfolio mix)</td>
<td>0.38</td>
</tr>
<tr>
<td>$\xi \times 100$ Adjustment cost (change in portfolio mix)</td>
<td>5.97</td>
</tr>
<tr>
<td>$q$ Lower bound on balance sheet</td>
<td>0</td>
</tr>
<tr>
<td>$\bar{q}$ Upper bound on balance sheet</td>
<td>0.7</td>
</tr>
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- **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**
  - $\chi \Leftarrow$ long-term debt duration is 10 years; $\delta$ and $\Theta$ from pre-GFC UK data (DMO)
  - $\bar{q}$ based on BoE purchase limits (Logan and Blindseil, 2019); $q = 0$
Parameter values

Impulse response matching

- $\nu, \xi$ chosen to match SVAR response to QE shock (Weale and Wieladek, 2016)
- Initial ‘kink’ in long rate response $\Leftrightarrow \xi$ 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

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<th>MPC / FOMC behaviour</th>
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<td>✓</td>
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<td>Policy rate is ‘active instrument’ away from ELB</td>
<td>✓</td>
</tr>
<tr>
<td>QT starts after policy rate lifts off from ELB</td>
<td>✗</td>
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- 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

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<td>QT starts after policy rate lifts off from ELB</td>
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▶ Suppose instead central bank minimises ‘flexible inflation targeting’ loss function

\[ L_{t}^{FIT} = \mathbb{E}_{t} \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left( \omega_{x} \hat{x}_{\tau}^{2} + \omega_{\pi} \hat{\pi}_{\tau}^{2} \right) \]

▶ 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

(a) Losses for flexible inflation targeting strategies as $\rho$ varies

$\rho$

Flexible inflation targeting

Slower QT $\Leftrightarrow$ larger $\rho$
Flexible inflation targeting and QT

(a) Losses for flexible inflation targeting strategies as $\rho$ varies

- Passive unwind $\Rightarrow$ substantial welfare costs
Flexible inflation targeting and QT

- ‘Neutral’ unwind ($\tilde{q}_t = 0$ 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, $\tilde{q} = 0.7$)
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

- 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 $\chi$ each period
  - Implies similar pricing equations to Woodford (2001) bond
  - Facilitates analysis of ‘passive unwind’ of QE
Fiscal policy and QE

- 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)
  - ⇒ neutrality w.r.t. central bank balance sheet

- Assumptions mirror key aspects of UK approach to QE
  - Indemnification of APF ⇒ fiscal support (Del Negro and Sims, 2015)
  - Chancellor letter to DMO re issuance strategy
Nominal government budget constraint:

\[ B_t + V_t \tilde{D}_t = R^B_{t-1} B_{t-1} + (1 - \chi + \chi V_t) \tilde{D}_{t-1} - \Omega^C_t - P_t \tau_t \]

- \( B = \) short-term debt (T-bills)
- \( \tilde{D} = \) long-term debt (\( D \equiv V \times \tilde{D} \) is market value of debt)
- \( \Omega^C = \) remittances from/to central bank
- \( \tau = \) net tax/transfer payments from/to households
Fiscal policy and QE

Central bank

- Central bank budget constraint:
\[
\Omega_t^C = Z_t - R_{t-1}^Z Z_{t-1} - \left( V_t \tilde{D}_t^C - (1 - \chi + \chi V_t) \tilde{D}_{t-1}^C \right)
\]

- Central bank balance sheet constraint:
\[
V_t \tilde{D}_t^C = Z_t
\]

- Combining:
\[
\Omega_t^C = \frac{1 - \chi + \chi V_t}{V_{t-1}} V_{t-1} \tilde{D}_{t-1}^C - R_{t-1}^Z Z_{t-1} = \left[ R_{t-1}^D - R_{t-1}^Z \right] Z_{t-1}
\]
\[
\equiv R_{t-1}^D, \quad \equiv R_{1,t}^D
\]

⇒ remittances are determined by portfolio revaluation effects
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.*

⇒ 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)

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

- Maximizes real profits discounted by marginal utility ($\Lambda$)

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

- Subject to a balance sheet constraint:

$$
S_t \geq B_t^l + D_t^l + Z_t^l
$$

- Nominal profit is:

$$
\Omega_t^l = S_t - B_t^l - D_t^l - Z_t^l + R_{t-1} Z_{t-1}^l + R_{t-1}^B B_{t-1}^l + R_{t}^D D_{t-1}^l
$$

$$
- R_{t-1}^S S_{t-1} - (z^l + b^l + d^l) P_t \mathcal{M} (\delta \rho_t^l)
$$

$$
- (z^l + b^l + d^l) P_t \mathcal{A} (\rho_t^l - \rho_{t-1}^l)
$$

where $\rho_t^l \equiv \frac{Z_t^l + B_t^l}{D_t^l}$
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
  - $\hat{R} \geq \ln \beta$ (zero lower bound)
  - $q \geq 0$ (central bank cannot issue long bonds)
  - $q \leq \bar{q} \leq 1$ (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

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

subject to:

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

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

\[ \hat{R}_t \geq \ln \beta \]

\[ q_t \geq 0 \]

\[ q_t \leq \bar{q} \]
The Lagrangean

\[
\min_{\{\hat{\pi}_t, \hat{x}_t, \hat{R}_t, q_t\}} \frac{\omega_x}{2} \hat{x}_t^2 + \frac{\omega\pi}{2} \hat{\pi}_t^2 + \frac{\omega q}{2} q_t^2 + \frac{\omega \Delta q}{2} (q_t - q_{t-1})^2 + \beta E_t \mathcal{L}_{t+1} (q_t) \\
- \lambda_t^\pi (\hat{\pi}_t - \kappa \hat{x}_t - \beta E_t \Pi (q_t) - u_t) \\
- \lambda_t^x \left( \hat{x}_t - E_t X (q_t) + \sigma \left( \hat{R}_t - E_t \Pi (q_t) - \gamma q_t + \xi q_{t-1} + \beta \xi E_t Q (q_t) - r_t^* \right) \right) \\
- \lambda_t^R \left( \hat{R}_t - \ln \beta \right) - \lambda_t^q (q_t - \bar{q}) - \lambda_t^q (q_t - q)
\]

- Policymaker accounts for effects of $q_t$ via $X$, $\Pi$ and $Q$
- Policymaker takes (functions) $X$, $\Pi$ and $Q$ 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 QE can be written as

$$0 = \Theta \tilde{q}_t + \beta \sigma \xi E_t \lambda^X_{t+1} + \beta D_t^\Pi \omega_\pi \hat{\pi}_t$$

$$- \left[ D_t^X + \sigma D_t^\Pi + \sigma \gamma - \beta \sigma \xi D_t^Q \right] \lambda^X_t - \lambda^{\tilde{q}}_t - \lambda_t^q$$

where

$$D_t^Z \equiv \frac{\partial E_t Z_{t+1}}{\partial q_t}$$

for $Z = \{\Pi, X, Q\}$ and $\lambda^X, \lambda^\pi, \lambda^{\tilde{q}}, \lambda^q$ 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

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

$$\Theta^{-1} q_t = -\sigma (\omega x \hat{x}_t + \kappa \omega \pi \hat{\pi}_t)$$

Marginal cost of using QE  Marginal cost of deviating from NK optimality condition

2. If bounds on QE never bind, $D_t^X = D_t^\Pi = 0, D_t^Q = D^Q$:

$$\Theta \tilde{q}_t = -\beta \sigma \xi E_t^{\lambda^X} \lambda^X_{t+1} + \left[ \sigma \gamma - \beta \sigma \xi D^Q \right] \lambda^X_t$$

⇒ require ZLB ($\lambda^X > 0$) for $\tilde{q}_t \neq 0$

⇒ $\tilde{q}_t < 0$ when ZLB ‘weakly binds’ ($\lambda^X \approx 0; E_t^{\lambda^X} \lambda^X_{t+1} > 0$) ⇒ start QT before liftoff

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

⇒ when far away from ZLB $\tilde{q}_t \approx 0$
Policy functions

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
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

$q$ distribution mostly $< \bar{q}$; $\Delta q$ 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

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

<table>
<thead>
<tr>
<th></th>
<th>Time consistent</th>
<th>Commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \hat{R} ) and ( q )</td>
<td>( \hat{R} ) only</td>
</tr>
<tr>
<td>Quarterly inflation, %</td>
<td>-0.02</td>
<td>-0.07</td>
</tr>
<tr>
<td>Output gap, %</td>
<td>-0.01</td>
<td>-0.02</td>
</tr>
<tr>
<td>Policy rate, annualized %</td>
<td>3.06</td>
<td>2.75</td>
</tr>
<tr>
<td>Long-term rate, annualized %</td>
<td>2.82</td>
<td>2.75</td>
</tr>
<tr>
<td>QE (( q ))</td>
<td>0.09</td>
<td>0.00</td>
</tr>
<tr>
<td>Loss (( \times 100 ))</td>
<td>0.60</td>
<td>0.82</td>
</tr>
<tr>
<td>Relative loss</td>
<td>1.38</td>
<td>1.89</td>
</tr>
<tr>
<td>ZLB frequency, %</td>
<td>38</td>
<td>40</td>
</tr>
</tbody>
</table>
Flexible inflation targeting with alternative QT strategies

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


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References


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