The Reanchoring Channel of QE
The ECB’s Asset Purchase Programme and Long-Term Inflation Expectations

Philippe Andrade    Johannes Breckenfelder
Fiorella De Fiore    Peter Karadi    Oreste Tristani

European Central Bank*

Bank of Italy,
Oct 2016

*The views expressed are those of the authors, and do not necessarily reflect the official position of the ECB or the Eurosystem.
Overview

- Large-scale asset purchases (LSAP)
  - Key policy tool of all major central banks
  - Substitute for interest rates stuck at their effective lower bound (ZLB)
Overview

- Large-scale asset purchases (LSAP)
  - Key policy tool of all major central banks
  - Substitute for interest rates stuck at their effective lower bound (ZLB)

- In a frictionless world, LSAP no impact (Curdia and Woodford, 2011)
Overview

- Large-scale asset purchases (LSAP)
  - Key policy tool of all major central banks
  - Substitute for interest rates stuck at their effective lower bound (ZLB)

- In a frictionless world, LSAP no impact (Curdia and Woodford, 2011)

- In practice, significant announcement effects (Krishnamurthy and Vissing-Jorgensen, 2011; Altavilla, Carboni and Motto, 2015)
Overview

▶ Large-scale asset purchases (LSAP)
  ▶ Key policy tool of all major central banks
  ▶ Substitute for interest rates stuck at their effective lower bound (ZLB)

▶ In a frictionless world, LSAP no impact (Curdia and Woodford, 2011)

▶ In practice, significant announcement effects (Krishnamurthy and Vissing-Jorgensen, 2011; Altavilla, Carboni and Motto, 2015)

▶ Our focus: Impact on long-term inflation expectations at the ZLB
  ▶ Adverse shocks at the ZLB led to some deanchoring in 2013-2014 in EA
  ▶ Initial LSAP announcement in 2015:1 contributed to reanchoring
This paper

- Event-study evidence on ECB’s LSAP (APP) announcements on inflation expectations
  - Unconventional easing leads to subsequent rise in 5-year-ahead inflation expectations
This paper

- Event-study evidence on ECB’s LSAP (APP) announcements on inflation expectations
  - Unconventional easing leads to subsequent rise in 5-year-ahead inflation expectations

- DSGE model with
  - Balance-sheet constrained financial intermediaries
  - Binding effective lower bound
  - Imperfect information about CB’s target
This paper

- Event-study evidence on ECB’s LSAP (APP) announcements on inflation expectations
  - Unconventional easing leads to subsequent rise in 5-year-ahead inflation expectations

- DSGE model with
  - Balance-sheet constrained financial intermediaries
  - Binding effective lower bound
  - Imperfect information about CB’s target

- Calibrated to the euro area
  - Quantifies the importance of the reanchoring channel of APP
  - Shock w/o policy action: downturn and deanchoring
  - APP stimulates the economy and leads to reanchoring
Findings

- Reanchoring channel is potent
  - Explains 1/3 of the inflation impact of APP
  - Amplified impact on short-term inflation
  - Mechanism (ZLB and financial accelerator):
    - Higher target implies easier policy
    - Leads to higher expected inflation
    - Implies lower real rates now (ZLB, even though earlier liftoff)
    - Raises asset prices, eases financial constraints in a positive feedback loop
Findings

- Reanchoring channel is potent
  - Explains 1/3 of the inflation impact of APP
  - Amplified impact on short-term inflation
  - Mechanism (ZLB and financial accelerator):
    - Higher target implies easier policy
    - Leads to higher expected inflation
    - Implies lower real rates now (ZLB, even though earlier liftoff)
    - Raises asset prices, eases financial constraints in a positive feedback loop

- Implications
  - Target uncertainty renders policy passivity costly
  - Makes credible policy signals powerful
Reanchoring Channel: Related Literature

- Event-study evidence on QE
  - Broad asset-price impact (Rogers, Scotti and Wright, 2014; Swanson, 2015)
  - Scarce evidence on impact on long-term inflation expectations
    - Market expectations (Krishnamurthy and Vissing-Jorgensen, 2011; Altavilla, Carboni and Motto, 2015): premium component
Reanchoring Channel: Related Literature

- Event-study evidence on QE
  - Broad asset-price impact (Rogers, Scotti and Wright, 2014; Swanson, 2015)
  - Scarce evidence on impact on long-term inflation expectations
    - Market expectations (Krishnamurthy and Vissing-Jorgensen, 2011; Altavilla, Carboni and Motto, 2015): premium component

- Information in introducing QE
  - Related to signalling at ZLB (Bhattarai, Eggertsson and Gafarov, 2015)
    - There: QE helps commitment of discretionary CB
    - Here: QE reveals information about policy rule (Gürkaynak, Sack and Swanson, 2005; Gürkaynak, Levin and Swanson, 2010)
  - Complements ‘asset-revaluation’ channels (Gertler and Karadi, 2013; Del Negro, Eggertsson, Ferrero and Kiyotaki, 2010; Chen, Cúrdia and Ferrero, 2012)
EA event study

- ECB press conferences
  - January 2013 - December 2015
  - Special ECB: IR announcements separate from press conferences
  - Press conferences (36)
  - Robustness: exclude 3 with key FG announcements (June 5, 2014; October 22, 2015; March 10, 2016)
EA event study

- ECB press conferences
  - January 2013 - December 2015
  - Special ECB: IR announcements separate from press conferences
  - Press conferences (36)
  - Robustness: exclude 3 with key FG announcements (June 5, 2014; October 22, 2015; March 10, 2016)

- Measurement of the monetary policy indicator
  - 5-year German bund yield
  - Market price: average of the best bid and ask quotes, from the last 5
  - Surprise: price change between 10 minutes before, 80 minutes after the start of the press conference
  - Cumulated over each quarter
EA event study, cont

- Inflation expectations
  - 5-year ahead inflation expectations in the SPF
  - Robustness: 5-year inflation swap yields 5-year-ahead
EA event study, cont

- Inflation expectations
  - 5-year ahead inflation expectations in the SPF
  - Robustness: 5-year inflation swap yields 5-year-ahead

- Methodology: Quarterly regressions

\[ \Delta y_t = \alpha + \beta \Delta x_{t-1} + \varepsilon_t, \]
Impact on 5-year inflation expectations

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post 2013</td>
<td>Pre 2013</td>
<td>APP</td>
<td>APP, No FG</td>
</tr>
<tr>
<td>Change in 5-year-ahead inflation expectations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-year German yield surprise</td>
<td>-0.599*** (-4.392)</td>
<td>0.0932 (1.551)</td>
<td>-0.583** (-3.151)</td>
<td>-0.508*** (-3.960)</td>
</tr>
<tr>
<td>Sample</td>
<td>2013q1-2016q2</td>
<td>2001q1-2012q4</td>
<td>2014q2-2016q2</td>
<td>2014q2-2016q2</td>
</tr>
<tr>
<td>Observations</td>
<td>15</td>
<td>47</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.523</td>
<td>0.051</td>
<td>0.457</td>
<td>0.539</td>
</tr>
</tbody>
</table>

Robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

- Easing yields to reanchoring
- Robustness: ILS
Overview

- Quantitative DSGE model
  - Representative family with Households
    - Consumption habits
    - Monopolistically competitive labor market; staggered wage setting
    - Portfolio adjustment costs HH assets
  - Intermediate good producers with ‘working capital constraint’ Intermediate
  - Capital producers with investment adjustment costs \((Q)\) Capital
  - Monopolistically competitive retailers with staggered price setting Retailers
Overview

- Quantitative DSGE model
  - Representative family with Households
    - Consumption habits
    - Monopolistically competitive labor market; staggered wage setting
    - Portfolio adjustment costs HH assets
  - Intermediate good producers with ‘working capital constraint’ Intermediate
  - Capital producers with investment adjustment costs \((Q)\) Capital
  - Monopolistically competitive retailers with staggered price setting Retailers

- Balance sheet constrained financial intermediaries
Overview

➤ Quantitative DSGE model
  ➤ Representative family with Households
    ➤ Consumption habits
    ➤ Monopolistically competitive labor market; staggered wage setting
    ➤ Portfolio adjustment costs HH assets
  ➤ Intermediate good producers with ‘working capital constraint’ Intermediate
  ➤ Capital producers with investment adjustment costs ($Q$) Capital
  ➤ Monopolistically competitive retailers with staggered price setting Retailers
  ➤ Balance sheet constrained financial intermediaries
  ➤ Central bank with uncertain inflation target
Financial intermediaries

- Representative family
  - $f$ bankers, $1 - f$ workers
  - Bankers: start-up fund $X$, stochastic survival $\sigma$
Financial intermediaries

- Representative family
  - \( f \) bankers, \( 1 - f \) workers
  - Bankers: start-up fund \( X \), stochastic survival \( \sigma \)

- Assets:
  - State-contingent loans \( (Q_t S_t) \): \( R_{kt} \)
  - Long-term government bond \( (q_t B_t) \): \( R_{bt} \)
Financial intermediaries

- Financial intermediaries
  - Collect deposits from HHs: $D_t$
  - Accumulate net worth from retained earnings $N_t$
  - Invest them into loans and government bonds
Financial intermediaries

- Financial intermediaries
  - Collect deposits from HHs: $D_t$
  - Accumulate net worth from retained earnings $N_t$
  - Invest them into loans and government bonds

- Agency problem: bankers can divert
  - the fraction $\theta$ of loans and
  - $\Delta \theta$ of gov’t bonds, with $0 \leq \Delta \leq 1$. 
Implications

- ‘Risk-adjusted’ aggregate leverage constraint

\[ Q_t S_{pt} + \Delta q_t B_{pt} \leq \phi_t N_t \]

where \( \phi_t \) is an endogenous leverage ratio.
Implications

- ‘Risk-adjusted’ aggregate leverage constraint

\[ Q_t S_{pt} + \Delta q_t B_{pt} \leq \phi_t N_t \]

where \( \phi_t \) is an endogenous leverage ratio.

- ‘Arbitrage’ between corporate and sovereign bonds

\[ \Delta E_t \beta \tilde{\Omega}_{t+1}(R_{kt+1} - R_{t+1}) = E_t \beta \tilde{\Omega}_{t+1}(R_{bt+1} - R_{t+1}) , \]

where \( \tilde{\Omega}_{t+1} \) the FI’s discount factor.
Implications

- ‘Risk-adjusted’ aggregate leverage constraint

\[ Q_t S_{pt} + \Delta q_t B_{pt} \leq \phi_t N_t \]

where \( \phi_t \) is an endogenous leverage ratio.

- ‘Arbitrage’ between corporate and sovereign bonds

\[ \Delta E_t/\beta \tilde{\Omega}_{t+1}(R_{kt+1} - R_{t+1}) = E_t/\beta \tilde{\Omega}_{t+1}(R_{bt+1} - R_{t+1}), \]

where \( \tilde{\Omega}_{t+1} \) the FI’s discount factor.

- Aggregate net worth

\[ N_t = \sigma \left[ (R_{kt} - R_t)Q_{t-1}S_{pt-1} + (R_{bt} - R_t)q_{t-1}B_{pt-1} + R_t N_{t-1} \right] + X \]
Credit Policy

- Central bank: Less efficient in providing credit
  - $\tau$ efficiency cost
Credit Policy

- Central bank: Less efficient in providing credit
  - $\tau$ efficiency cost

- Not balance sheet constrained
Credit Policy

- Central bank: Less efficient in providing credit
  - $\tau$ efficiency cost

- Not balance sheet constrained

- Asset purchases
  - Gov’t: Reducing the supply of long-term assets
  - Private: Direct credit to the private sector
Credit Policy, cont.

- Composition of Assets between banks and central bank

\[
S_t = S_{pt} + S_{gt} \\
B_t = B_{pt} + B_{gt}
\]
Credit Policy, cont.

- Composition of Assets between banks and central bank

\[ S_t = S_{pt} + S_{gt} \]
\[ B_t = B_{pt} + B_{gt} \]

- Private Securities Demand

\[ Q_t S_t = \phi_t N_t + Q_t S_{gt} + \Delta q_t (B_{gt} - B_t) \]
Credit Policy, cont.

- Composition of Assets between banks and central bank

\[ S_t = S_{pt} + S_{gt} \]
\[ B_t = B_{pt} + B_{gt} \]

- Private Securities Demand

\[ Q_t S_t = \phi_t N_t + Q_t S_{gt} + \Delta q_t (B_{gt} - B_t) \]

- Purchases of gov’t bonds have:
  - weaker effects on private vs. gov’t securities demand
  - stronger effects on excess returns of private vs. gov’t sec.
Central Bank

- LSAP: $\Psi_t = (Q_t S_{gt} + \Delta q_t B_{gt})/4\bar{Y}$
  - Follows a second-order autoregressive process
Central Bank

- LSAP: \( \Psi_t = \left( Q_t S_{gt} + \Delta q_t B_{gt} \right) / 4\bar{Y} \)
  - Follows a second-order autoregressive process

- Interest rate policy with ZLB: \( i_t \)
  \[
  i_t = \max(0, i^*_t) \\
  i^*_t = \rho_i i_{t-1} + (1 - \rho_i) \left[ \pi^*_t + \kappa_\pi (\pi_t - \pi^*_t) + \kappa_y y_t \right] + \kappa_{\Delta \pi} (\pi_t - \pi_{t-1}) + \kappa_{\Delta y} (y_t - y_{t-1}) + \varepsilon_t \\
  \pi^*_t = \rho_{\pi} \pi^*_{t-1} + \varepsilon^\pi_t 
  \]
Central Bank

- **LSAP**: $\Psi_t = (Q_t S_{gt} + \Delta q_t B_{gt}) / 4\bar{Y}$
  - Follows a second-order autoregressive process

- **Interest rate policy with ZLB**: $i_t$
  
  $$i_t = \max(0, i^*_t)$$
  $$i^*_t = \rho_i i_{t-1} + (1 - \rho_i) \left[ \pi^*_t + \kappa_\pi (\pi_t - \pi^*_t) + \kappa_y y_t \right] + \kappa_{\Delta \pi} (\pi_t - \pi_{t-1}) + \kappa_{\Delta y} (y_t - y_{t-1}) + \epsilon_t$$
  $$\pi^*_t = \rho_\pi \pi^*_{t-1} + \epsilon^\pi_t$$

- Conventional and unconventional policies are substitutes
  - Effective lower bound on the interest rate
  - LSAP unconstrained
Learning

- Imperfect information: $\pi_t^*, \varepsilon_t$ are unobserved
Learning

- Imperfect information: $\pi_t^*, \varepsilon_t$ are unobserved

- Learning rule,

\[
\pi_{t+1}^{*e} = \rho \pi \pi_t^{*e} - \kappa \left\{ i_t - i_t^e - \varsigma (\Psi_t - \Psi_t^e) - (1 - \rho_i)\kappa_{\pi} + \kappa_{\Delta \pi} \right\} \left( \pi_t - \pi_t^e \right) \\
+ [(1 - \rho_i)\kappa_y + \kappa_{\Delta y}] \left( y_t - y_t^e \right)
\]
Learning

- Imperfect information: $\pi_t^*, \varepsilon_t$ are unobserved

- Learning rule,

$$\pi_{t+1}^e = \rho \pi_t^e \pi_t^e - \kappa \{i_t - i_t^e - \varsigma(\Psi_t - \Psi_t^e) -$$

$$\left[(1 - \rho_i)\kappa_{\pi} + \kappa_{\Delta\pi}\right](\pi_t - \pi_t^e)$$

$$\left[(1 - \rho_i)\kappa_{\pi} + \kappa_{\Delta\pi}\right](\pi_t - \pi_t^e)$$

$$\left[(1 - \rho_i)\kappa_{\pi} + \kappa_{\Delta\pi}\right](\pi_t - \pi_t^e)$$

$$\left[(1 - \rho_i)\kappa_{\pi} + \kappa_{\Delta\pi}\right](\pi_t - \pi_t^e)$$

- Idea

  - Motivated by constant gain ($\kappa$) learning
  - Agents assume LSAP substitutes IRs at the ZLB,

$$i_t^S = i_t - \varsigma \Psi_t$$
Learning

- Imperfect information: $\pi^*_t, \varepsilon_t$ are unobserved

- Learning rule,

\[
\pi^*_{t+1} = \rho \pi \pi^*_t - \kappa \left\{ i_t - i^e_t - \varsigma (\Psi_t - \Psi^e_t) - \\
(1 - \rho_i) \kappa_i \pi_t + \kappa_\Delta \pi \right\} (\pi_t - \pi^e_t) \\
[(1 - \rho_i) \kappa_y + \kappa_\Delta y] (y_t - y^e_t)
\]

- Idea
  - Motivated by constant gain ($\kappa$) learning
  - Agents assume LSAP substitutes IRs at the ZLB,
    \[
i^S_t = i_t - \varsigma \Psi_t
\]

- Reanchoring
  - At ZLB $i_t = i^e_t$ w/o LSAP, low inflation leads to deanchoring
  - LSAP: $\Psi_t > \Psi^e_t$ leads to reanchoring
Solution

- Learning equilibrium
  - Agents optimize, learn about CB target
  - CB sets LSAP policy and interest rates s.t. ZLB
  - All markets clear
Solution

- Learning equilibrium
  - Agents optimize, learn about CB target
  - CB sets LSAP policy and interest rates s.t. ZLB
  - All markets clear

- First-order appr. solution: impulse response analysis
  - Optimality conditions loglinearized around a non-stochastic steady state
  - Shocks hit in period 1
  - Inflation target stays unchanged (unknown to agents)
  - ZLB binds endogenously (non-linearity)
Solution

- Learning equilibrium
  - Agents optimize, learn about CB target
  - CB sets LSAP policy and interest rates s.t. ZLB
  - All markets clear

- First-order appr. solution: impulse response analysis
  - Optimality conditions loglinearized around a non-stochastic steady state
  - Shocks hit in period 1
  - Inflation target stays unchanged (unknown to agents)
  - ZLB binds endogenously (non-linearity)

- Algorithm: solution over the impulse response space
  - Each period: Update expectations about the inflation target
  - Forecast perceived responses (including the length ZLB is expected to bind)
  - Consume, work, save, invest, set prices, wages now
  - IR policy is set according to a constant inflation target
  - Repeat each period until steady state reached
Calibration

- Tightness of credit conditions
  - Average credit spreads
    - Private: 2.45% (LT CCB - Eonia)
    - Sovereign: 2.1% (EA 10-year yield - Eonia)
  - FI leverage: 6
    - Assets over equity of FIs, NFCs in EA SA
Calibration

- Tightness of credit conditions
  - Average credit spreads
    - Private: 2.45% (LT CCB - Eonia)
    - Sovereign: 2.1% (EA 10-year yield - Eonia)
  - FI leverage: 6
    - Assets over equity of FIs, NFCs in EA SA

- Learning rule
  - 15bps decline in LT expectations before APP ($\kappa = 0.062$)
  - Similar impact of APP and 1.1% monpol shock ($\varsigma = 0.068$)
  - 9bps increase on APP announcement (consistent with SPF change between 2015Q1-Q3)
Calibration, cont.

- Conventional parameters
  - Price- and wage stickiness, consumption habits, investment adjustment costs, policy rule
  - As estimated in NAWM (Christoffel et al., 2008)
  - High nominal stickiness
Calibration, cont.

- Conventional parameters
  - Price- and wage stickiness, consumption habits, investment adjustment costs, policy rule
  - As estimated in NAWM (Christoffel et al., 2008)
  - High nominal stickiness

- APP
  - 11% of GDP, maturity: 8, 9% in ten-year equivalents
  - Hump-shaped pattern
  - Calibrated to reach peak in 2 years, exit as bonds mature
Results

- Stylized demand shock
  - Persistent shock to savings preference
  - Inflation: $-2.4\%$, Output $-7\%$, 10-year rate $-100\text{bps}$
  - Deanchoring: perceived target $-15 \text{ bps}$, expected liftoff: 7 quarters
Results

- **Stylized demand shock**
  - Persistent shock to savings preference
  - Inflation: $-2.4\%$, Output $-7\%$, 10-year rate $-100$bps
  - Deanchoring: perceived target $-15$ bps, expected liftoff: 7 quarters

- **APP**
  - Peak effects: inflation $40$bps, output: $1.1\%$
  - Important channel: reanchoring (1/3 of inflation effect)
  - Alternative calibration: inflation $25$bps, output $50$bps, reanchoring $1/2$ of inflation effect
  - Equivalent to a $-1.1\%$ monpol shock
Results

- **Stylized demand shock**  
  - Persistent shock to savings preference  
  - Inflation: $-2.4\%$, Output $-7\%$, 10-year rate $-100\text{bps}$  
  - Deanchoring: perceived target $-15\text{ bps}$, expected liftoff: 7 quarters

- **APP**  
  - Peak effects: inflation 40bps, output: 1.1%  
  - Important channel: reanchoring (1/3 of inflation effect)  
  - Alternative calibration: inflation 25bps, output 50bps, reanchoring 1/2 of inflation effect  
  - Equivalent to a $-1.1\%$ monpol shock

- **Raising efficiency**  
  - Maturity extension (from 8 to 11, +10bps inflation effect)  
  - Forward guidance (+5 bps inflation effect)
Other channels

- Duration channel

Figure
Other channels

- Duration channel
- “Stealth recapitalization”
Conclusion

- Inflation-expectation reanchoring: key channel
  - Event-study evidence
  - Quantified in a DSGE macromodel
Conclusion

- Inflation-expectation reanchoring: key channel
  - Event-study evidence
  - Quantified in a DSGE macromodel

- Policy conclusions
  - Inactivity particularly costly with deanchoring
  - Reanchoring enhances policy effectiveness
  - Duration of targeted assets should be maximized
  - Forward guidance reinforces the effectiveness of APP
Euro Area Inflation Expectations

Euro Area Inflation Expectations

Impact on 5x5 inflation-linked swap rates

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post 2013</td>
<td>Pre 2013</td>
<td>APP</td>
<td>APP, No FG</td>
</tr>
<tr>
<td>Change in 5x5 inflation-linked swap yields</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-year German yield</td>
<td>-1.222**</td>
<td>0.571***</td>
<td>-1.533**</td>
<td>-1.189**</td>
</tr>
<tr>
<td>surprise</td>
<td>(-2.754)</td>
<td>(4.303)</td>
<td>(-2.592)</td>
<td>(-2.571)</td>
</tr>
<tr>
<td>Sample</td>
<td>2013q1-2016q2</td>
<td>2004q1-2012q4</td>
<td>2014q2-2016q2</td>
<td>2014q2-2016q2</td>
</tr>
<tr>
<td>Observations</td>
<td>15</td>
<td>34</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.315</td>
<td>0.176</td>
<td>0.426</td>
<td>0.399</td>
</tr>
<tr>
<td>Robust t-statistics in parentheses</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*** p&lt;0.01, ** p&lt;0.05, * p&lt;0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Easing yields to reanchoring
Impact of an interest rate innovation
Demand shock and APP

The graphs illustrate the effects of a demand shock and APP on various economic indicators.

- **Savings preference**: The savings preference decreases over time, indicating a shift towards spending.
- **CB purchases**: Central bank purchases increase, affecting the economy.
- **Policy rate**: The policy rate remains relatively stable, showing the central bank's response to the shock.
- **Inflation**: Inflation decreases, reflecting the demand shock.
- **Output**: Output decreases initially, then stabilizes.
- **Consumption**: Consumption decreases initially, then stabilizes.
- **Investment**: Investment decreases, affecting economic activity.
- **Asset Price**: Asset prices decrease, impacting market dynamics.
- **Banks Market Capitalization**: Capitalization remains stable, indicating resilience.
- **10 year rate**: The 10-year rate decreases, reflecting market expectations.
- **Perceived Inflation Target**: The perceived inflation target decreases, aligning with macroeconomic policy.
- **Expected Liftoff**: Expected liftoff is delayed, reflecting the central bank's stimulus.

The graphs compare the baseline scenario with the no policy scenario, highlighting the impact of APP.
APP and maturity extension

![Graphs showing the impact of policy rate, CB purchases, savings preference, viscosity, inflation, output, consumption, investment, asset price, banks market capitalization, 10-year rate, perceived inflation target, and expected liftoff over quarters. The graphs compare baseline with maturity extension scenarios.]
APP with and without reanchoring channel
APP and monetary policy shock

![Graphs showing the effects of APP and a monetary policy shock on CB purchases, output, inflation, policy rate, consumption, investment, asset price, 10-year rate, and perceived inflation objective. The graphs compare Baseline (solid line) and Monetary policy shock (-110bps) (dashed line) over 20 quarters.](image-url)
APP and forward guidance

CB purchases

Policy rate

Inflation

Baseline

APP with Forward Guidance

Output

10 year rate

Expected Liftoff

% of GDP

% impact

Quarters

Quarters

Quarters

Expected Liftoff

Quarters


Gertler, Mark and Peter Karadi (2013) “QE 1 vs. 2 vs. 3...: A Framework for Analyzing Large-Scale Asset Purchases as a Monetary Policy Tool,” International Journal of Central Banking, Vol. 9, pp. 5–53.
References III


Hachula, Michael, Michele Piffer, and Malte Rieth (2016) “Unconventional Monetary Policy, Fiscal Side Effects, and Euro Area (Im) balances.”


Households

- Maximize utility

\[
E_t \sum_{i=0}^{\infty} \beta^i \left[ \ln(C_{t+i} - hC_{t+i-1}) - \frac{\chi}{1 + \varphi} L_{t+i}^{1+\varphi} \right]
\]

- subject to

\[C_t + D_{ht+1} = W_t L_t + \Pi_t + T_t + R_t D_t\]

- where
  - \(D_{ht}\): short term debt (deposits and government debt)
  - \(\Pi_t\): payouts to the household from firm ownership net the transfers it gives to the bankers
Wage setting

- Labor supply is a composite of heterogeneous labor services

\[
N_t = \left[ \int_0^1 N_{ft} \frac{e^W - 1}{e^W} df \right]^{\frac{e^W}{e^W - 1}}
\]

where \( N_{ft} \) is the supply of labor service \( f \).
**Wage setting**

- Labor supply is a composite of heterogeneous labor services

\[ N_t = \left[ \int_0^1 N_{ft} \frac{\epsilon^W - 1}{\epsilon^W} df \right]^{\epsilon^W} \epsilon^W - 1 \tag{1} \]

where \( N_{ft} \) is the supply of labor service \( f \).

- From cost minimization by firms:

\[ N_{ft} = \left( \frac{W_{ft}}{W_t} \right)^{-\epsilon^W} N_t \tag{2} \]
Wage setting

- Labor supply is a composite of heterogeneous labor services

\[ N_t = \left[ \int_0^1 N_{ft} \frac{\varepsilon W - 1}{\varepsilon W} df \right]^{\frac{\varepsilon W}{\varepsilon W - 1}} \]  

where \( N_{ft} \) is the supply of labor service \( f \).

- From cost minimization by firms:

\[ N_{ft} = \left( \frac{W_{ft}}{W_t} \right)^{-\varepsilon W} N_t \]  

- Staggered wage setting a la Calvo
  - Wages can be adjusted with probability \( 1 - \gamma_W \)
  - Indexation with probability \( \gamma_W \) (\( \Pi_t^{\dagger} \))
Wage Setting

▶ Optimal Wage Setting

\[ \sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t+i} \left[ \frac{W_t \Pi^\dagger_{t,t+i}}{P_{t+i}} - \mu W N_{ft+i}^\varphi \right] N_{ft+i} = 0 \quad (3) \]

with \( \mu W = \frac{1}{1-1/\varepsilon_W} \).
Wage Setting

- Optimal Wage Setting

$$\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t+i} \left[ \frac{W_t \Pi_{t,t+i}^\dagger}{P_{t+i}} - \mu W N^{\varphi}_{ft+i} \right] N_{ft+i} = 0 \quad (3)$$

with $\mu W = \frac{1}{1-1/\varepsilon_W}$. 
Wage Setting

- **Optimal Wage Setting**

\[
\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t+i} \left[ \frac{W_t \Pi_{t,t+i}^\dagger}{P_{t+i}} - \mu W N_{f,t+i}^\varphi \right] N_{f,t+i} = 0 \quad (3)
\]

with \( \mu W = \frac{1}{1-1/\varepsilon_W} \).

- **From the law of large numbers,**

\[
W_t = \left[ (1 - \gamma W)(W_t^*)^{1-\varepsilon_W} + \gamma W (\Pi_{t-1} \Pi_t^{1-\gamma W} P_{t-1})^{1-\varepsilon_W} \right]^{1-\varepsilon_W} \quad (4)
\]
Household Asset Holdings

Households can directly hold private securities and long-term gov’t bonds subject to transactions costs

- Private: holding costs: $\frac{1}{2} \kappa (S_{ht} - \bar{S}_h)^2$ for $S_{ht} \geq \bar{S}_h$.
- Gov’t bonds: holding cost: $\frac{1}{2} \kappa (B_{ht} - \bar{B}_h)^2$ for $B_{ht} \geq \bar{B}_h$
Household Asset Holdings

- Households can directly hold private securities and long-term gov’t bonds subject to transactions costs
  - Private: holding costs: \( \frac{1}{2} \kappa (S_{ht} - \bar{S}_h)^2 \) for \( S_{ht} \geq \bar{S}_h \).
  - Gov’t bonds: holding cost: \( \frac{1}{2} \kappa (B_{ht} - \bar{B}_h)^2 \) for \( B_{ht} \geq \bar{B}_h \).

- Household asset demands:

\[
S_{ht} = \bar{S}_h + \frac{E_t \Lambda_{t,t+1}(R_{kt+1} - R_{t+1})}{\kappa} \\
B_{ht} = \bar{B}_h + \frac{E_t \Lambda_{t,t+1}(R_{bt+1} - R_{t+1})}{\kappa}
\]
Household Asset Holdings

- Households can directly hold private securities and long-term gov’t bonds subject to transactions costs
  - Private: holding costs: $\frac{1}{2}\kappa(S_h - \overline{S}_h)^2$ for $S_h \geq \overline{S}_h$.
  - Gov’t bonds: holding cost: $\frac{1}{2}\kappa(B_h - \overline{B}_h)^2$ for $B_h \geq \overline{B}_h$

- Household asset demands:
  \[
  S_{ht} = \overline{S}_h + \frac{E_t \Lambda_{t,t+1}(R_{kt+1} - R_{t+1})}{\kappa} \\
  B_{ht} = \overline{B}_h + \frac{E_t \Lambda_{t,t+1}(R_{bt+1} - R_{t+1})}{\kappa}
  \]

- Elasticity $\kappa$
  - the excess returns go to zero as $\kappa \to 0$,
  - the quantities go to their frictionless values as $\kappa \to \infty$. 


Credit policy with HH asset demand

▶ Composition of Assets

\[ S_t = S_{pt} + S_{ht} + S_{gt} \]

\[ B_t = B_{pt} + B_{ht} + B_{gt} \]
Credit policy with HH asset demand

- Composition of Assets

\[ S_t = S_{pt} + S_{ht} + S_{gt} \]

\[ B_t = B_{pt} + B_{ht} + B_{gt} \]

- Private Asset Demands

\[ Q_t(S_t - S_h) = \phi_t N_t + Q_t S_{gt} + \Delta q_t \left[ B_{gt} - (B_t - \bar{B}_h) \right] + \]

\[ (Q_t + \Delta^2 q_t) \frac{E_t \Lambda_{t,t+1}(R_{kt+1} - R_{t+1})}{\kappa} \]
Credit policy with HH asset demand, cont.

- Relative effects of securities versus govt’ bond purchases similar to before.
- Larger effects of purchases with fixed demand.
- Responses of household asset demands can moderate effects.
- Overall, need limits to arbitrage for bank and household asset demands.
Households

- Representative family
  - $f$ bankers, $1 - f$ workers
  - Perfect consumption insurance

With iid. probability $1 - \sigma$, a banker becomes a worker. (Limits bankers’ ability to save themselves out of the financial constraints)

Each period, $(1 - \sigma) f$ workers randomly become bankers

New banker receives a start-up fund from the family
Households

- Representative family
  - $f$ bankers, $1 - f$ workers
  - Perfect consumption insurance

- With iid. probability $1 - \sigma$, a banker becomes a worker.
  (Limits bankers’ ability to save themselves out of the financial constraints)
Households

- Representative family
  - $f$ bankers, $1 - f$ workers
  - Perfect consumption insurance

- With iid. probability $1 - \sigma$, a banker becomes a worker. (Limits bankers’ ability to save themselves out of the financial constraints)

- Each period, $(1 - \sigma)f$ workers randomly become bankers
Households

- Representative family
  - $f$ bankers, $1 - f$ workers
  - Perfect consumption insurance

- With iid. probability $1 - \sigma$, a banker becomes a worker. (Limits bankers’ ability to save themselves out of the financial constraints)

- Each period, $(1 - \sigma)f$ workers randomly become bankers

- New banker receives a start-up fund from the family
Assets

- Return on state-contingent debt (capital)

\[ R_{kt+1} = \frac{Z_{t+1} + Q_{t+1}}{Q_t} \]
Assets

- Return on state-contingent debt (capital)

\[ R_{kt+1} = \frac{Z_{t+1} + Q_{t+1}}{Q_t} \]

- Return on long term gov’t bonds

\[ R_{bt+1} = \frac{\Xi / P_t + q_{t+1}}{q_t} \]
Financial Intermediaries

- Intermediary Balance Sheet

\[ Q_t s_t + q_t b_t = n_t + d_t \]
Financial Intermediaries

- Intermediary Balance Sheet

\[ Q_t s_t + q_t b_t = n_t + d_t \]

- Evolution of net worth

\[ n_t = R_{kt} Q_{t-1} s_{t-1} + R_{bt} q_{t-1} b_{t-1} - R_t d_{t-1} \]
Financial Intermediaries

- Intermediary Balance Sheet

\[ Q_t s_t + q_t b_t = n_t + d_t \]

- Evolution of net worth

\[ n_t = R_{kt} Q_{t-1} s_{t-1} + R_{bt} q_{t-1} b_{t-1} - R_t d_{t-1} \]

- FI’s objective

\[ V_t = E_t \sum_{i=1}^{\infty} (1 - \sigma)\sigma^{i-1} \Lambda_{t,t+i} n_{t+i} \]  \hspace{1cm} (5)
Limits to Arbitrage

- Agency problem: banker can divert
  - the fraction $\theta$ of loans and
  - $\Delta \theta$ of gov’t bonds, with $0 \leq \Delta \leq 1$. 

\[ V_t \geq \theta Q_t + \Delta \theta q_t b_t. \] (6)
Limits to Arbitrage

- Agency problem: banker can divert
  - the fraction $\theta$ of loans and
  - $\Delta \theta$ of gov’t bonds, with $0 \leq \Delta \leq 1$.

- Lenders can recover the residual funds and shut the bank down.
Limits to Arbitrage

- Agency problem: banker can divert
  - the fraction $\theta$ of loans and
  - $\Delta \theta$ of gov’t bonds, with $0 \leq \Delta \leq 1$.

- Lenders can recover the residual funds and shut the bank down.

- Incentive constraint

\[
V_t \geq \theta Q_t s_t + \Delta \theta q_t b_t. \tag{6}
\]
▶ ‘Risk-adjusted’ leverage constraint

\[ Q_t s_t + \Delta q_t b_t = \phi_t n_t \]

where \( \phi_t \) is an endogenous leverage ratio.
Implications

- ‘Risk-adjusted’ leverage constraint

\[ Q_{ts} + \Delta q_t b_t = \phi_t n_t \]

where \( \phi_t \) is an endogenous leverage ratio.

- ‘Arbitrage’ between corporate and sovereign bonds

\[ \Delta E_t \beta \tilde{\Omega}_{t+1} (R_{kt+1} - R_{t+1}) = E_t \beta \tilde{\Omega}_{t+1} (R_{bt+1} - R_{t+1}), \]

where \( \tilde{\Omega}_{t+1} \) the FI’s discount factor.
Aggregation

- Aggregate leverage

\[ Q_t S_{pt} + \Delta q_t B_{pt} \leq \phi_t N_t \]
Aggregation

- Aggregate leverage

\[ Q_tS_{pt} + \Delta q_tB_{pt} \leq \phi_tN_t \]

- Aggregate net worth

\[ N_t = \sigma [(R_{kt} - R_t)Q_{t-1}S_{pt-1} + (R_{bt} - R_t)q_{t-1}B_{pt-1} + R_tN_{t-1}] + X \]
Resource Constraint and Government Policy

- Resource constraint

\[ Y_t = C_t + I_t + f \left( \frac{I_t}{I_{t-1}} \right) I_t + G + \Phi_t \]

where \( \Phi_t \) is the portfolio transactions costs.
Resource Constraint and Government Policy

- Resource constraint

\[ Y_t = C_t + I_t + f \left( \frac{I_t}{I_{t-1}} \right) I_t + G + \Phi_t \]

where \( \Phi_t \) is the portfolio transactions costs.

- Central bank balance sheet

\[ Q_t S_{gt} + q_t B_{gt} = D_{gt} \]
Resource Constraint and Government Policy

- Resource constraint

\[
Y_t = C_t + I_t + f \left( \frac{I_t}{I_{t-1}} \right) I_t + G + \Phi_t
\]

where \( \Phi_t \) is the portfolio transactions costs.

- Central bank balance sheet

\[
Q_t S_{gt} + q_t B_{gt} = D_{gt}
\]

- Gov’t budget constraint

\[
G = T_t + (R_{kt} - R_t - \tau) S_{gt-1} + (R_{bt} - R_t) B_{gt-1}
\]
Financial Intermediaries’ Problem

- End-of-period value function $V_t$

$$V_{t-1}(s_{t-1}, b_{t-1}, n_{t-1}) = E_{t-1} \Lambda_{t-1,t} \{(1 - \sigma)n_t + \sigma W_t(n_t)\}$$
Financial Intermediaries’ Problem

- **End-of-period value function** $V_t$

  $V_{t-1}(s_{t-1}, b_{t-1}, n_{t-1}) = E_{t-1} \Lambda_{t-1,t} \{(1 - \sigma)n_t + \sigma W_t(n_t)\}$

- **Beginning-of-period value function** $W_t$

  $W_t(n_t) = \max_{s_t, b_t} V_t(s_t, b_t, n_t)$

  subject to $[\lambda_t]$

  $V_t(s_t, b_t, n_t) \geq \theta Q_t s_t + \Delta \theta q_t b_t$
Solution

- Conjecture: linear end-of-period value function

\[ V_t = \mu_{st} Q_t s_t + \mu_{bt} q_t b_t + \nu_t n_t \]
Solution

- Conjecture: linear end-of-period value function
  \[ V_t = \mu_{st}Q_t s_t + \mu_{bt}q_t b_t + \nu_t n_t \]

- Beginning-of-period Lagrange function
  \[ (1 + \lambda_t)(\mu_{st}Q_t s_t + \mu_{bt}q_t b_t + \nu_t n_t) - \lambda_t(\theta Q_t s_t + \Delta \theta q_t b_t) \]
Solution, cont.

- **FONC: \( s_t \)**

  \[
  \mu_{st} = \frac{\lambda_t}{1 + \lambda_t} \theta
  \]

- **FONC: \( b_t \)**

  \[
  \mu_{bt} = \Delta \frac{\lambda_t}{1 + \lambda_t} \theta = \Delta \mu_{st}
  \]

- **FONC: \( \lambda_t \)**

  \[
  (\mu_{st} Q_t s_t + \mu_{bt} q_t b_t + \nu_t n_t) - (\theta Q_t s_t + \Delta \theta q_t b_t) = 0
  \]
Solution, cont.

- Endogenous ‘risk-adjusted’ leverage constraint:

\[ Q_t s_t + \Delta q_t b_t = \phi_t n_t \]

where \( \phi_t \) is the leverage ratio:

\[ \phi_t = \frac{\nu_t}{\theta - \mu_{st}} \]
Solution, cont.

- **Endogenous ‘risk-adjusted’ leverage constraint:**

\[ Q_t s_t + \Delta q_t b_t = \phi_t n_t \]

where \( \phi_t \) is the leverage ratio:

\[ \phi_t = \frac{\nu_t}{\theta - \mu_{st}} \]

- **Beginning-of-period value function**

\[ W_t(n_t) = \mu_{st} (Q_t s_t^* + \Delta q_t b_t^*) + \nu_t n_t \]

\[ = (\mu_{st} \phi_t + \nu_t) n_t \]

\[ = \theta \phi_t n_t \]
Solution, cont.

- End-of-period value function

\[
\mu_{st-1}Q_{t-1}s_{t-1} + \mu_{bt-1}q_{t-1}b_{t-1} + \nu_{t-1}n_{t-1} = \\
E_{t-1}\Lambda_{t-1,t}\{(1 - \sigma)n_t + \sigma W_t(n_t)\},
\]

subject to

\[
n_t = (R_{kt} - R_t)Q_{t-1}s_{t-1} + (R_{bt} - R_t)q_{t-1}b_{t-1} + R_t n_{t-1}
\]
Solution, cont.

- End-of-period value function

\[
\mu_{st-1} Q_{t-1} s_{t-1} + \mu_{bt-1} q_{t-1} b_{t-1} + \nu_{t-1} n_{t-1} = \\
E_{t-1} \Lambda_{t-1,t} \{(1 - \sigma)n_t + \sigma W_t(n_t)\},
\]

subject to

\[
n_t = (R_{kt} - R_t) Q_{t-1} s_{t-1} + (R_{bt} - R_t) q_{t-1} b_{t-1} + R_t n_{t-1}
\]

- After substitution

\[
\mu_{st-1} Q_{t-1} s_{t-1} + \mu_{bt-1} q_{t-1} b_{t-1} + \nu_{t-1} n_{t-1} = \\
E_{t-1} \Lambda_{t-1,t} \{(1 - \sigma) + \sigma \theta \phi_t\} \\
(R_{kt} - R_t) Q_{t-1} s_{t-1} + (R_{bt} - R_t) q_{t-1} b_{t-1} + R_t n_{t-1}\},
\]
Solution, cont.

- Partial marginal values

\[
\mu_{st} = E_t \tilde{\Omega}_{t+1} (R_{kt+1} - R_{t+1})
\]

\[
\mu_{bt} = E_t \tilde{\Omega}_{t+1} (R_{bt+1} - R_{t+1}) = \Delta \mu_{st}
\]

\[
\nu_t = E_t \tilde{\Omega}_{t+1} R_{t+1}
\]

\[
\tilde{\Omega}_t = \Lambda_{t,t+1} [1 - \sigma + \sigma \theta \phi_t]
\]

where \( \tilde{\Omega}_t > 1 \) is the FI’s discount factor.
Solution, cont.

- Partial marginal values

\[
\begin{align*}
\mu_{st} &= E_t \tilde{\Omega}_{t+1} (R_{kt+1} - R_{t+1}) \\
\mu_{bt} &= E_t \tilde{\Omega}_{t+1} (R_{bt+1} - R_{t+1}) = \Delta \mu_{st} \\
\nu_t &= E_t \tilde{\Omega}_{t+1} R_{t+1} \\
\tilde{\Omega}_t &= \Lambda_{t,t+1} [1 - \sigma + \sigma \theta \phi_t]
\end{align*}
\]

where \( \tilde{\Omega}_t > 1 \) is the FI’s discount factor.

- End-of-period value function is indeed linear.
Capital producers

- Profit Maximization

\[
\max E_t \sum_{\tau=t}^{\infty} \beta^t \Lambda_{t,\tau} \left\{ (Q_{\tau} - 1)I_{\tau} - f \left( \frac{I_{\tau} + I}{I_{\tau-1}} \right) (I_{\tau}) \right\} \tag{7}
\]

where \( f(1) = f'(1) = 0 \) and \( f''(1) > 0 \).
Capital producers

- Profit Maximization

\[
\max E_t \sum_{\tau=t}^{\infty} \beta^t \Lambda_{t,\tau} \left\{ (Q_\tau - 1) I_\tau - f \left( \frac{I_\tau + I}{I_{\tau-1}} \right) (I_\tau) \right\} \tag{7}
\]

where \( f(1) = f'(1) = 0 \) and \( f''(1) > 0 \).

- “Q” relation for investment:

\[
Q_t = 1 + f(\cdot) + \frac{I_t}{I_{t-1}} f'(\cdot) - E_t \beta \Lambda_{t,t+1} \left( \frac{I_{t+1}}{I_t} \right)^2 f'(\cdot) \tag{8}
\]
Intermediate Goods Producer

- Production

\[ Y_t = A_t (K_t)^\alpha L_t^{1-\alpha} \]  \hspace{1cm} (9)
Intermediate Goods Producer

- Production
  \[ Y_t = A_t (K_t)^\alpha L_t^{1-\alpha} \] (9)

- Evolution of firm capital
  \[ K_{t+1} = [I_t + (1 - \delta)K_t] \]
Intermediate Goods Producer

- Production
  \[ Y_t = A_t(K_t)^\alpha L_t^{1-\alpha} \] (9)

- Evolution of firm capital
  \[ K_{t+1} = [I_t + (1 - \delta)K_t] \]

- Share issue
  \[ S_t = K_{t+1} \]
Intermediate Goods Producers, cont.

- **FONC labor:**
  \[ P_{mt}(1 - \alpha) \frac{Y_t}{L_t} = W_t, \]  
  \[ P_{mt} \] be the price of intermediate goods output

- **Capital rental**
  \[ Z_t = P_{mt} \alpha \frac{Y_{t+1}}{K_{t+1}} - \delta, \]
  the replacement price of used capital is fixed at unity.
Retailers and price setting

- Final output as a composite of retail output

\[ Y_t = \left[ \int_0^1 Y_{ft} \frac{\varepsilon-1}{\varepsilon} df \right]^{\frac{\varepsilon}{\varepsilon-1}} \]  \hspace{1cm} (11)

where \( Y_{ft} \) is output by retailer \( f \).
Retailers and price setting

- Final output as a composite of retail output

\[ Y_t = \left[ \int_0^1 Y_{ft} \frac{\varepsilon-1}{\varepsilon} df \right] \frac{\varepsilon}{\varepsilon-1} \]  

(11)

where \( Y_{ft} \) is output by retailer \( f \).

- From cost minimization by users of final output:

\[ Y_{ft} = \left( \frac{P_{ft}}{P_t} \right)^{-\varepsilon} Y_t \]  

(12)
Retailers and price setting

- Final output as a composite of retail output

\[
Y_t = \left[ \int_0^1 Y_{ft} \frac{\varepsilon - 1}{\varepsilon} df \right]^{\frac{\varepsilon}{\varepsilon - 1}}
\]  
(11)

where \(Y_{ft}\) is output by retailer \(f\).

- From cost minimization by users of final output:

\[
Y_{ft} = \left( \frac{P_{ft}}{P_t} \right)^{-\varepsilon} Y_t
\]

(12)

- Staggered price setting a la Calvo
  - Price can be adjusted with probability \(1 - \gamma\)
  - Indexation with probability \(\gamma\)
    - Partially \((1 - \gamma_P)\) to target \(\Pi_t^*\),
    - Partially \((\gamma_P)\) to past inflation \(\Pi_{t-1}\)
    - \(\Pi_t^\dagger = \Pi_t^{*1-\gamma_P} \Pi_t^{\gamma_P}\)
Price Setting

* Price Setting Problem

\[
\max \sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[ \frac{P_t^* \Pi_{t,t+i}^\dagger}{P_{t+i}} - P_{m_t+i} \right] Y_{f_t+i} \tag{13}
\]
Price Setting

- Price Setting Problem

$$\max \sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[ \frac{P_t^* \Pi^\dagger_{t,t+i}}{P_{t+i}} - P_{mt+i} \right] Y_{ft+i}$$  \hspace{1cm} (13)

- Optimal Price Setting

$$\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[ \frac{P_t^* \Pi^\dagger_{t,t+i}}{P_{t+i}} - \mu P_{mt+i} \right] Y_{ft+i} = 0$$  \hspace{1cm} (14)

with $\mu = \frac{1}{1-1/\varepsilon}$.
Price Setting

- Price Setting Problem

\[
\max \sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[ \frac{P_t^* \Pi^\dagger_{t,t+i}}{P_{t+i}} - P_{mt+i} \right] Y_{ft+i} \tag{13}
\]

- Optimal Price Setting

\[
\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[ \frac{P_t^* \Pi^\dagger_{t,t+i}}{P_{t+i}} - \mu P_{mt+i} \right] Y_{ft+i} = 0 \tag{14}
\]

with \( \mu = \frac{1}{1-1/\varepsilon} \).

- From the law of large numbers,

\[
P_t = \left[ (1 - \gamma)(P_t^*)^{1-\varepsilon} + \gamma (\prod_{t-1}^{\gamma} \Pi_t^{1-\gamma} P_{t-1})^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \tag{15}
\]
### Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta )</td>
<td>0.994</td>
<td>Discount rate</td>
</tr>
<tr>
<td>( h )</td>
<td>0.567</td>
<td>Habit parameter</td>
</tr>
<tr>
<td>( \chi )</td>
<td>20.758</td>
<td>Relative utility weight of labor</td>
</tr>
<tr>
<td>( B/Y )</td>
<td>0.700</td>
<td>Steady state Treasury supply</td>
</tr>
<tr>
<td>( \bar{K}^h/K )</td>
<td>0.000</td>
<td>Proportion of direct capital holdings of the HHs</td>
</tr>
<tr>
<td>( \tilde{B}^h/B )</td>
<td>0.750</td>
<td>Proportion of long term Treasury holdings of the HHs</td>
</tr>
<tr>
<td>( \kappa )</td>
<td>1.000</td>
<td>Portfolio adjustment cost</td>
</tr>
<tr>
<td>( \varphi )</td>
<td>2.000</td>
<td>Inverse Frisch elasticity of labor supply</td>
</tr>
<tr>
<td>( \epsilon_W )</td>
<td>4.333</td>
<td>Elasticity of labor substitution</td>
</tr>
<tr>
<td>( \gamma_W )</td>
<td>0.765</td>
<td>Probability of keeping the wage constant</td>
</tr>
<tr>
<td>( \gamma_{W,-1} )</td>
<td>0.635</td>
<td>Wage indexation parameter</td>
</tr>
<tr>
<td>( \rho_{\pi^*p} )</td>
<td>0.990</td>
<td>Persistence of a shock to the perceived inflation objective</td>
</tr>
<tr>
<td>( \kappa )</td>
<td>0.0622</td>
<td>Kalman-gain</td>
</tr>
<tr>
<td>( \zeta )</td>
<td>0.0683</td>
<td>Relative weight of APP surprise</td>
</tr>
<tr>
<td>( \theta )</td>
<td>0.315</td>
<td>Fraction of capital that can be diverted</td>
</tr>
<tr>
<td>( \Delta )</td>
<td>0.840</td>
<td>Proportional advantage in seizure rate of government debt</td>
</tr>
<tr>
<td>( \omega )</td>
<td>0.0047</td>
<td>Proportional transfer to the entering bankers</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>0.925</td>
<td>Survival rate of the bankers</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>0.360</td>
<td>Capital share</td>
</tr>
<tr>
<td>( \delta )</td>
<td>0.025</td>
<td>Depreciation rate</td>
</tr>
</tbody>
</table>
Parameters, cont.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta_i )</td>
<td>5.169</td>
<td>Inverse elasticity of net investment to the price of capital</td>
</tr>
<tr>
<td>( \epsilon )</td>
<td>3.857</td>
<td>Elasticity of substitution</td>
</tr>
<tr>
<td>( \gamma_P )</td>
<td>0.920</td>
<td>Probability of keeping the price constant</td>
</tr>
<tr>
<td>( \gamma_{P,-1} )</td>
<td>0.417</td>
<td>Price indexation parameter</td>
</tr>
<tr>
<td>( G/Y )</td>
<td>0.200</td>
<td>Steady state proportion of government expenditures</td>
</tr>
<tr>
<td>( \rho_i )</td>
<td>0.865</td>
<td>Interest rate smoothing parameter</td>
</tr>
<tr>
<td>( \kappa_\pi )</td>
<td>1.904</td>
<td>Inflation coefficient in the policy rule</td>
</tr>
<tr>
<td>( \kappa_{d\pi} )</td>
<td>0.185</td>
<td>Inflation growth coefficient in the policy rule</td>
</tr>
<tr>
<td>( \kappa_{dy} )</td>
<td>0.147</td>
<td>Output growth coefficient in the policy rule</td>
</tr>
<tr>
<td>( \rho_{i,zlb} )</td>
<td>0.500</td>
<td>Interest rate smoothing leaving the lower bound</td>
</tr>
<tr>
<td>( \gamma_\psi )</td>
<td>0.290</td>
<td>Share of private assets in the purchase program</td>
</tr>
<tr>
<td>( \psi )</td>
<td>0.018</td>
<td>Initial asset purchase shock</td>
</tr>
<tr>
<td>( \rho_{1,\psi} )</td>
<td>1.700</td>
<td>First AR coefficient of the purchase shock</td>
</tr>
<tr>
<td>( \rho_{2,\psi} )</td>
<td>-0.710</td>
<td>Second AR coefficient of the purchase shock</td>
</tr>
<tr>
<td>( e_\beta )</td>
<td>0.044</td>
<td>Initial savings preference shock (( \beta ))</td>
</tr>
<tr>
<td>( \rho_\beta )</td>
<td>0.815</td>
<td>Persistence of the savings preference shock (( \beta ))</td>
</tr>
</tbody>
</table>
Bond yields around announcement and implementation

- Both announcement and implementation of the PSPP have sizable impact on yields
- High duration bonds are impacted significantly more
- Not only purchased bonds show lower yields (no scarcity channel)
Impact of purchases on bond yields

- No significant effect of individual trades on daily yield changes (excludes first two weeks)
- Three different setups: (i) simple panel, (ii) event study around the first purchase, (iii) black-out period
- No differential impact of trading intensity (several measures)
- Stringent controls: time FE, bond FE.

<table>
<thead>
<tr>
<th></th>
<th>Trading effect</th>
<th>First purchase effect</th>
<th>Blackout period effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>purchase dummy</td>
<td>relative purchases</td>
<td></td>
</tr>
<tr>
<td>purchase effect</td>
<td>-0.021</td>
<td>0.059</td>
<td>0.019</td>
</tr>
<tr>
<td>(0.041)</td>
<td>(0.087)</td>
<td>(0.038)</td>
<td>(0.327)</td>
</tr>
<tr>
<td>purchase intensity (perc. 25-50)</td>
<td>0.016</td>
<td>(0.255)</td>
<td></td>
</tr>
<tr>
<td>purchase intensity (perc. 50-75)</td>
<td>-0.278</td>
<td>(0.265)</td>
<td></td>
</tr>
<tr>
<td>purchase intensity (perc. 75-100)</td>
<td>-0.094</td>
<td>(0.265)</td>
<td></td>
</tr>
<tr>
<td>purchase effect × April</td>
<td>0.317</td>
<td>0.446</td>
<td></td>
</tr>
<tr>
<td>(0.357)</td>
<td>(0.339)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>purchase effect × May</td>
<td>0.067</td>
<td>0.696*</td>
<td></td>
</tr>
<tr>
<td>(0.110)</td>
<td>(0.262)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>purchase effect × June</td>
<td>0.029</td>
<td>0.680*</td>
<td></td>
</tr>
<tr>
<td>(0.119)</td>
<td>(0.349)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>purchase effect × July</td>
<td>-0.481***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.144)</td>
<td>(0.342)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>purchase effect × Aug</td>
<td>0.105</td>
<td>0.363</td>
<td></td>
</tr>
<tr>
<td>(0.095)</td>
<td>(0.332)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>purchase effect × Sep</td>
<td>-0.278**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.119)</td>
<td>(0.349)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>purchase effect × Oct</td>
<td>-0.210**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.097)</td>
<td>(0.334)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>purchase effect × Nov</td>
<td>-0.285***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.099)</td>
<td>(0.335)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>purchase effect × Dec</td>
<td>0.238**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.108)</td>
<td>(0.418)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>913,091</td>
<td>913,091</td>
<td>913,044</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.0236</td>
<td>0.0236</td>
<td>0.0236</td>
</tr>
<tr>
<td>Bond FE</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>daily Time FE</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Cluster Bond</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>
The impact of the PSPP on euro area banks

- QE as a form of bank capital relief: the larger the sovereign bonds holdings, the larger the benefits

- Event study: reaction of each bank’s stock price to PSPP announcement. Focus on quoted banks with info on govt bond holdings (as of end-2014). SNL data, 150 banks.

- 2-day changes: January 21-23; March 4-6

- Need to control for:
  - Broader effects on discounted future profits through improvement in macroeconomic conditions
    - Proxy: increase in country’s stock price index
  - Impact of flattened yield curve on interest rate margins
    - Proxy 1: change in 10-yr govt yield
    - Proxy 2: dummy=1 if bank located in EA

- Support of bank capital relief in Jan 2015.
Equity price reactions between January 21 and 23, 2015 (SNL sample)

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>constant</td>
<td>2.55***</td>
<td>2.09***</td>
<td>1.74***</td>
</tr>
<tr>
<td></td>
<td>(4.38)</td>
<td>(3.81)</td>
<td>(3.21)</td>
</tr>
<tr>
<td>Δyield</td>
<td>15.67***</td>
<td>9.12***</td>
<td>8.76***</td>
</tr>
<tr>
<td></td>
<td>(4.61)</td>
<td>(2.83)</td>
<td>(2.76)</td>
</tr>
<tr>
<td>ΔSM</td>
<td>0.39***</td>
<td>0.80***</td>
<td>0.77***</td>
</tr>
<tr>
<td></td>
<td>(2.88)</td>
<td>(3.96)</td>
<td>(4.54)</td>
</tr>
<tr>
<td>EA bank (d)</td>
<td>-2.23***</td>
<td>-2.56***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-3.65)</td>
<td>(-4.69)</td>
<td></td>
</tr>
<tr>
<td>exposure</td>
<td></td>
<td></td>
<td>0.06***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2.73)</td>
</tr>
<tr>
<td>Adj. $R^2$</td>
<td>0.09</td>
<td>0.19</td>
<td>0.26</td>
</tr>
<tr>
<td>No. Obs.</td>
<td>150</td>
<td>150</td>
<td>120</td>
</tr>
</tbody>
</table>

*(White robust t-statistics)*
Signal of lower future policy rates

- Impact on average expectation from SPF
  - 2015Q1-2015Q3: MRO rate forecasts declined from 11 to 6bps for 2016 and from 43 to 31bps for 2017

- What do low interest rates mean? (Andrade et al., 2015)
  - Policy will be more accommodative
  - Outlook worse than thought: Trap will last longer

- Which one prevailed?
  - Estimate individual pre-crisis interest rate rule; panel regression over 1999Q1-2007Q4
  - Compare observed individual policy rate forecast with forecasts consistent with individual policy rule
  - On average APP associated with expected future accommodation
Expected deviations from normal times policy

Source: ECB SPF and Own calculations
Risk of reduced effectiveness of the APP

- Increased issuance of long-term bonds by national governments would raise investors’ exposure to duration risk, offsetting the impact of APP.

- Following announcement of PSPP, average maturity of newly issued eligible bonds relative to maturing bonds rose by approx 2 yrs.

- Combined effect on duration risk is a reduction, over 2015Q1-Q4:
  - Govt issuance increased supply of 10-yrs equivalent debt by 1.9 percent of GDP.
  - PSPP reduced it by 4.5 percent of GDP.
Limits to the effectiveness

All eligible issuers

All maturities

Maturity of at least 2 years

Maturity below 2 years

Back