Optimal Monetary Policy in a Data-Rich Environment

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DSGE Models in the Policy Environment
Banca d'Italia

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Monetary Policy in Practice vs. DSGE Models

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- Most DSGE studies assume model known, state of economy perfectly observed
  - May exaggerate ability of CB to conduct stabilization policies
  - May distort welfare evaluations of alternative policies

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    - Why?

Why Monetary Policy in a Data-Rich Environment?

- Empirical evidence: large data sets relevant
  - for forecasting
    - Stock, Watson (1999, 2002); Forni, Hallin, Lippi, Reichlin (2000)...
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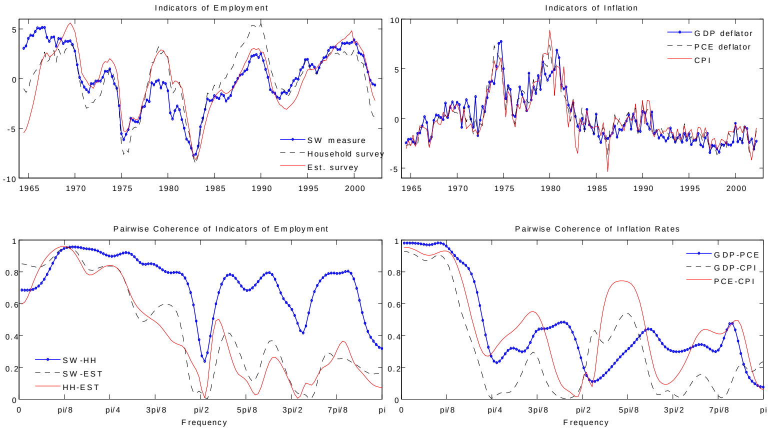
    - within quarter: Giannone, Monti, Reichlin (2008)
    - in quarterly data: Boivin-Giannoni (2006)

State of economy imperfectly observed

What is employment? What is inflation? (BG 2006)



- Employment: household surveys ≠ payroll surveys
- Inflation: GDP deflator, PCE deflator, CPI: low coherence at high frequency

Why monetary policy in a data-rich environment?

- BG (06): Estimation of DSGE model with large data set yields:
  - More precise estimation of the state of the economy
  - Improvements in "forecasting" with additional information
  - Different conclusions about sources of business cycles
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- Use of large data set should be desirable for conduct of monetary policy
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- What are welfare benefits of exploiting information from large data sets?

Paper's contributions

- Evaluate welfare benefits associated with exploiting information from large data sets for conduct of policy

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  - Finding: welfare gains may be large!
- Characterize equilibrium for optimal or arbitrary policies, given various information sets, in simple state-space form

Outline

1. Monetary policy under imperfect information
2. Econometrician's problem: Estimate states and parameters
3. Welfare implications of imperfect information in a simple quantitative model
4. Conclusion

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- Related work: Pearlman, Currie, Levine (1986), Pearlman (1992), Aoki (2003,2006), Svensson, Woodford (2003), Gerali, Lippi (2003)

General framework

- Model (Private sector):

$$\begin{bmatrix} Z_{t+1} \\ \tilde{E}\mathrm{E}_t z_{t+1} \end{bmatrix} = A \begin{bmatrix} Z_t \\ z_t \end{bmatrix} + Bi_t + \begin{bmatrix} u_{t+1} \\ 0 \end{bmatrix}$$

Assumption: private sector knows $\{Z_s, z_s, i_s, u_s, s \leq t\}$

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- CB sets instrument: i_t, observing X_s^{cb}, i_s, but not $Z_s, z_s, u_s, s \leq t$

$$X_t^{cb} = \Lambda \begin{bmatrix} Z_t \\ z_t \end{bmatrix} + v_t$$

Three cases

Central bank commits to simple rule

- Case #1: Responds naively to observed indicators:

$$i_t = \phi X_t^{cb} = \phi \Lambda \begin{bmatrix} Z_t \\ z_t \end{bmatrix} + (\phi v_t)$$

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- Case #2: Optimally filters information from observable indicators

$$i_t = \phi \begin{bmatrix} Z_{t|t} \\ z_{t|t} \end{bmatrix}$$

$$Z_{t|t} \equiv \mathrm{E}\left[Z_t | I_t^{cb} \right]$$

General framework

Central bank commits to optimal policy (Svensson Woodford, 2004)

- Case #3: CB minimizes loss

$$\mathcal{L}_0 = \mathrm{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\tau_t - \tau_t^*\right)' W \left(\tau_t - \tau_t^*\right) \ \middle| \ I_t^{cb} \right\}$$

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given:

- behavior of private sector
- CB observed indicators $\left(X_s^{cb}\right)$

Optimal policy in data-rich environment

- Complications due to asymmetry in information of private sector and CB:
  - certainty equivalence (pol. same as if eco fully observable): $\Longrightarrow$ modified (applies only to specific representation of policy)
  - separation principle (opt. pol vs signal-extraction): $\Longrightarrow$ does not apply
  - intuition: equilibrium depends of expected future variables (i.e., on how expected future policy will respond to signals)

Equilibrium characterization

- Solution in state space:

$$\begin{bmatrix} i_t \\ \bar{z}_t \end{bmatrix} = DS_t$$
$$S_t = GS_{t-1} + H\varepsilon_t$$

- Same form, whether:
  - policy is optimal or arbitrary rule
  - information is full or incomplete
- Dynamics entirely determined by state variables S_t

Equilibrium characterization: Examples

- Optimal policy (commitment), full information:

$$\begin{bmatrix} i_t \\ z_t \end{bmatrix} = \begin{bmatrix} \bar{D}_1 \\ \bar{D}_2 \end{bmatrix} \bar{Z}_t$$
$$\bar{Z}_t = \bar{G}_1 \bar{Z}_{t-1} + \bar{u}_t$$

where

$$S_t = \bar{Z}_t \equiv \begin{bmatrix} Z_t', & \Xi_{t-1}' \end{bmatrix}'$$

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- Optimal policy (commitment), imperfect information:

$$\begin{bmatrix} i_t \\ z_t \end{bmatrix} = \begin{bmatrix} 0 & \bar{D}_1 \\ \bar{D}_2^{\dagger} & (\bar{D}_2 - \bar{D}_2^{\dagger}) \end{bmatrix} \begin{bmatrix} \bar{Z}_t \\ \bar{Z}_{t|t} \end{bmatrix}$$
$$\begin{bmatrix} \bar{Z}_{t+1} \\ \bar{Z}_{t+1|t+1} \end{bmatrix} = \begin{bmatrix} \bar{G}_1^{\dagger} & (\bar{G}_1 - \bar{G}_1^{\dagger}) \\ \bar{K}\bar{L}\bar{G}_1^{\dagger} & (\bar{G}_1 - \bar{K}\bar{L}\bar{G}_1^{\dagger}) \end{bmatrix} \begin{bmatrix} \bar{Z}_t \\ \bar{Z}_{t|t} \end{bmatrix} + H \begin{bmatrix} \bar{u}_{t+1} \\ v_{t+1} \end{bmatrix}$$

Note: $\bar{D}_1, \bar{D}_2, \bar{G}_1$ independent of CB information set

Econometrician: Estimation of states and parameters

Linking theory and data: Known link

$$X_{F,t} = \Lambda_F F_t + e_{F,t} = \Lambda_F \Phi S_t + e_{F,t}$$

where $F_t = \Phi S_t$: variables of interest

- Concepts with multiple indicators:
  – e.g., Prices: GDP deflator, PCE deflator, CPI, ...

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  - No measurement error: $X_{F,t} = F_t = \Phi S_t$
  - Sargent (1989): $X_{F,t} = F_t + e_{F,t} = \Phi S_t + e_{F,t}$
    Maintain single indicator for each concept

Econometrician: Estimation of states and parameters

Linking theory and data: Unknown link

$$X_{S,t} = \Lambda_S S_t + e_{S,t}$$

where Λ_S is completely unrestricted (e.g. commodity prices)

- $X_{S,t}$ helps estimate the state vector S_t
- Partially observed state variables / exogenous shocks
  – E.g. productivity shock: oil or commodity prices may provide information
- More flexible exploitation of information

Empirical model: Summary

- Transition equation:

$$S_t = GS_{t-1} + H\varepsilon_t$$

- Observation equation:

$$X_t = \Lambda S_t + e_t$$

$$X_t \equiv \begin{bmatrix} X_{F,t} \\ X_{S,t} \end{bmatrix}, \qquad e_t \equiv \begin{bmatrix} e_{F,t} \\ e_{S,t} \end{bmatrix}, \qquad \Lambda \equiv \begin{bmatrix} \Lambda_F \Phi \\ \Lambda_S \end{bmatrix}.$$

- Comments:
  - Related to non-structural factor models, but we impose DSGE model on transition equation of latent factors
  - Factors have economic interpretation: state variables
  - Interpret info. in data set through lenses of DSGE model
  - Can do counterfactual experiments, study optimal policy

Advantages of large information set

Proposition 1: Suppose that the true model implies a transition equation of the form

$$S_t = GS_{t-1} + H\varepsilon_t$$

and that the data (X_t) relates to S_t according to

$$X_t = \Lambda S_t + e_t.$$

Then, under *suitable conditions* there exist estimates of S_t that have the property:

1. $\lim_{n_X \to +\infty} \hat{S}_t = S_t$
2. $\lim_{n_X \to +\infty} \text{var}(\hat{S}_t) = 0$

- Suitable conditions: Forni, Hallin, Lippi, Reichlin (2000), Stock Watson (2002), Forni, Giannone, Lippi, Reichlin (2005), Bai Ng (2006)

Advantages of large information set

Implications of proposition 1

Proposition 2: If CB conducts optimal policy under imperfect info. and estimates economy's states using an infinite data set ($n_X \to +\infty$), equilibrium is fully characterized by the state space characterizing the optimal equilibrium under full information

$$\begin{bmatrix} i_t \\ z_t \end{bmatrix} = \begin{bmatrix} \bar{D}_1 \\ \bar{D}_2 \end{bmatrix} \bar{Z}_t$$
$$\bar{Z}_{t+1} = \bar{G}_1 \bar{Z}_t + \bar{u}_{t+1},$$

where $\bar{D}_1, \bar{D}_2, \bar{G}_1$ depend on model in absence of uncertainty and $\bar{\Sigma}_u$ depends only on the structural shocks, even if $\Sigma_v \neq 0$. In addition

$$z_{t|t} = z_t, \quad \text{and} \quad \bar{Z}_{t|t} = \bar{Z}_t.$$

Welfare implications in a simple quantitative model

Model (Giannoni Woodford, 2004)

- Private sector: NK model with habit, price and wage rigidities, inflation indexing (but no decision delays)

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- IS block

$$\tilde{x}_t = E_t \tilde{x}_{t+1} - \varphi^{-1} \left(\hat{\imath}_t - E_t \pi_{t+1} - r_t^n \right)$$

$$\tilde{x}_t \equiv (x_t - \eta x_{t-1}) - \beta\eta \left(E_t x_{t+1} - \eta x_t \right)$$

$$x_t = y_t - y_t^n$$

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x_t &= y_t - y_t^n
\end{aligned}
$$

- AS block

$$
\begin{aligned}
\pi_t^w - \gamma_w \pi_{t-1} &= \xi_w \left(\omega_w x_t + \varphi \tilde{x}_t \right) + \xi_w \left(\omega_t^n - \omega_t \right) \\
&\quad + \beta \left(E_t \pi_{t+1}^w - \gamma_w \pi_t \right) \\
\pi_t - \gamma_p \pi_{t-1} &= \xi_p \omega_p x_t + \xi_p \left(\omega_t - \omega_t^n \right) + \beta \left(E_t \pi_{t+1} - \gamma_p \pi_t \right) \\
\pi_t^w &= \pi_t + \omega_t - \omega_{t-1}
\end{aligned}
$$

y_t^n, r_t^n, ω_t^n : functions of underlying shocks (TFP, gov. exp., labor supply)

Welfare implications in a simple quantitative model

Monetary policy

- Historical monetary policy

$$\hat{\imath}_t = \phi_{i1}\hat{\imath}_{t-1} + \phi_{i2}\hat{\imath}_{t-2} + (1 - \phi_{i1} - \phi_{i2})\left(\phi_\pi \pi_t^* + \phi_y y_t^* / 4\right) + \varepsilon_t^i$$

where π_t^*, y_t^* = indicators observable by CB

$$\begin{aligned} \pi_t^* &= \pi_t + e_t^\pi \\ y_t^* &= y_t + e_t^y \end{aligned}$$

Estimation of states

- Observation equation

$$
\begin{aligned}
X_{Ft} &= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & \lambda_2 \\ 0 & 0 & 0 & \lambda_3 \\ 0 & 0 & 0 & \lambda_4 \end{bmatrix} \begin{bmatrix} i_t \\ y_t \\ \omega_t \\ \pi_t \end{bmatrix} + \begin{bmatrix} 0 \\ e_t^y \\ e_t^w \\ e_t^{\pi 1} \\ e_t^{\pi 2} \\ e_t^{\pi 3} \\ e_t^{\pi 4} \end{bmatrix} \\
X_{St} &= \Lambda_S S_t + e_{St}
\end{aligned}
$$

where $X_{St} = 35$ PC of 91 US main macro time series

- Sample: 1982:1-2002:3
- Use MCMC techniques

"Estimation" of structural parameters: A short-cut

- In principle could estimate jointly states and parameters using MCMC algorithm (Boivin-Giannoni, 2006)
- Here: focus on the role of additional information for unobserved state
- Hence, "calibrate" structural parameters (at value obtained from standard Bayesian estimation)

"Estimation" of structural parameters: A short-cut

Model parameters

"Calibrated" parameters					
Structural parameters		*Historical policy rule*		*Persistence of shocks*	
β	0.9900	ϕ_{i1}	0.9124	ρ_a	0.7975
φ	3.7719	ϕ_{i2}	-0.1012	ρ_g	0.5046
η	0.7759	ϕ_π	2.0438	ρ_h	0.6444
γ_p	0.1506	$\phi_y/4$	0.1058	$\rho_{e\pi}$	0.9245
γ_ω	0.6661				
ξ_p	0.0543				
ξ_ω	0.1923				
ω_p	0.6046				
ω_w	0.6718				

Welfare loss function

- CB's welfare-relevant objective function

$$\mathcal{L}_0 = E_0 \left\{ (1-\beta) \sum_{t=0}^{\infty} \beta^t \left[\lambda_p \left(\pi_t - \gamma_p \pi_{t-1} \right)^2 \right.\right.$$
$$\left.\left. + \lambda_w \left(\pi_t^w - \gamma_w \pi_{t-1} \right)^2 + \lambda_x \left(x_t - \delta x_{t-1} \right)^2 + \lambda_i \hat{\imath}_t^2 \right] | I_0^{cb} \right\}$$

- Coefficients:

λ_p	λ_w	$16\lambda_x$	λ_i	δ
0.596	0.404	0.800	0.077	0.501

Welfare comparisons

Historical policy with alternative information sets

1. CB responds naively to observed indicators π_t^*, y_t^*

$$\hat{\imath}_t = \phi_{i1}\hat{\imath}_{t-1} + \phi_{i2}\hat{\imath}_{t-2} + (1 - \phi_{i1} - \phi_{i2})\left(\phi_\pi \pi_t^* + \phi_y y_t^*/4\right)$$

   not realizing that π_t^*, y_t^* are imperfect indicators of π_t, y_t

2. CB observes, π_s^*, $y_s^*, \hat{\imath}_s$, $s \leq t$, knows variance and persistence of measurement error, and optimally filters out noise

$$\hat{\imath}_t = \phi_{i1}\hat{\imath}_{t-1} + \phi_{i2}\hat{\imath}_{t-2} + (1 - \phi_{i1} - \phi_{i2})\left(\phi_\pi \pi_{t|t} + \phi_y y_{t|t}/4\right)$$

3. CB observe infinite number of data series = full info

$$\hat{\imath}_t = \phi_{i1}\hat{\imath}_{t-1} + \phi_{i2}\hat{\imath}_{t-2} + (1 - \phi_{i1} - \phi_{i2})\left(\phi_\pi \pi_t + \phi_y y_t/4\right)$$

Welfare comparisons

Historical policy with alternative information sets

Case	$E[\mathcal{L}_0]$	$V[\pi - \gamma_p \pi_{-1}]$	$V[\pi^w - \gamma_w \pi_{-1}]$	$V[x - \delta x_{-1}]$	$V[i]$
naive	7.70	8.21	4.21	0.85	5.48
simple filt.	2.74	2.40	1.54	0.71	1.63
full info.	2.05	1.85	0.95	0.53	1.73
Case 2/Case 3	1.34	1.30	1.62	1.32	0.94

Loss: **34% higher for CB doing simple filtering**

Note: with simple filtering, CB knows everything except for iid component of measurement error shock!

Welfare comparisons

Optimal policy with alternative information sets

Case	$E[\mathcal{L}_0]$	$V\left[\pi - \gamma_p \pi_{-1}\right]$	$V[\pi^w - \gamma_w \pi_{-1}]$	$V[x - \delta x_{-1}]$	$V[i]$
simple filt.	0.98	0.61	0.85	0.21	1.28
full info.	0.94	0.58	0.75	0.22	1.45
Case 2/Case 3	1.04	1.04	1.13	0.98	0.88

- Optimal policy: smaller welfare gains of large info set
  - Optimal policy more robust to imperfect info about state of economy
- Reasons to believe this underestimates welfare costs of imperfect info

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  - Adding trade-offs (markup shocks...) yields larger welfare effects

Conclusion

- Propose a general framework that exploits information from data-rich environment for:
  - estimation of DSGE models
  - optimal policy
- Imperfect measurement provides scope for using additional indicators
- Characterize equilibrium for optimal or arbitrary policies, given various information sets, in simple state-space form
- Attempt to automatize exercise informally done in CBs
- Finding: Properly exploiting all available information yields potentially large welfare benefits

Next steps planned

- Characterize optimal policy, optimal path of i_t ,π_t, y_t... given available info
- Available indicators give mixed signals
  $\Longrightarrow$ How to treat multiple signals? What weights?

Welfare comparisons

Alternative policies and information sets

Other statistics

Case		$V[\pi]$	$V[\pi^w]$	$V[y]$
Historical policy				
1	naive	10.81	11.74	4.86
2	simple filt.	2.95	2.64	3.59
3	full info.	2.26	1.60	3.86
	Case 2/Case 3	1.31	1.65	0.93
Optimal policy				
4	simple filt.	0.71	0.49	6.29
5	full info.	0.68	0.32	6.32
	Case 4/Case 5	1.05	1.54	0.99

"Estimation" of structural parameters: A short-cut

	St. dev. of shocks estimated with large data set
σ_a	1.4995
σ_g	0.0227
σ_h	0.9768
$\sigma_{\varepsilon i}$	0.2589
$\sigma_{e\pi}$	0.1880
σ_{ey}	0.0222