Optimal Monetary Policy in a Data-Rich Environment

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DSGE Models in the Policy Environment
Banca d'Italia

June 24, 2008
Monetary Policy in Practice vs. DSGE Models

- Monetary policy in practice: Complex because uncertainty about
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  - State of economy
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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
This paper

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- But state of economy imperfectly observed
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- Consider data-rich environment
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- But state of economy imperfectly observed
- Consider data-rich environment
  - Why?
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)
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- to assess state of economy: e.g.
  - within quarter: Giannone, Monti, Reichlin (2008)
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

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

- Assumptions:
Monetary policy under imperfect information

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  - model is true
Monetary policy under imperfect information

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  - agents know model, param. and state of economy (i.e., realized shocks)
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    - more accurate assessment of state by CB
    - should improve performance of policy, hence welfare
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    - more accurate assessment of state by CB
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General framework

Model (Private sector):

\[
\begin{bmatrix}
Z_{t+1} \\
\tilde{E}E_t z_{t+1}
\end{bmatrix} = A \begin{bmatrix} Z_t \\ z_t \end{bmatrix} + Bi_t + \begin{bmatrix} u_{t+1} \\ 0 \end{bmatrix}
\]

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

- Model (Private sector):

\[
\begin{bmatrix}
Z_{t+1} \\
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Z_{t} \\
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\end{bmatrix} + Bi_{t} + \begin{bmatrix}
u_{t+1} \\
0
\end{bmatrix}
\]

Assumption: private sector knows \(\{Z_{s}, z_{s}, i_{s}, u_{s}, s \leq t\}\)

- CB sets instrument: \(i_{t}\), observing \(X_{s}^{cb}, i_{s}\), but not \(Z_{s}, z_{s}, u_{s}, s \leq t\)

\[
X_{t}^{cb} = \Lambda \begin{bmatrix}
Z_{t} \\
z_{t}
\end{bmatrix} + \nu_{t}
\]
Three cases
Central bank commits to simple rule

- Case #1: Responds naively to observed indicators:

\[ i_t = \phi X_t^{cb} = \phi \Lambda \left[ \begin{array}{c} Z_t \\ z_t \end{array} \right] + (\phi v_t) \]
Three cases
Central bank commits to simple rule

- **Case #1**: Responds naively to observed indicators:
  \[
i_t = \phi X_{tcb} = \phi \Lambda \begin{bmatrix} Z_t \\ z_t \end{bmatrix} + (\phi v_t)
  \]

- **Case #2**: Optimally filters information from observable indicators
  \[
i_t = \phi \begin{bmatrix} Z_t|t \\ z_t|t \end{bmatrix}
  \]

\[
Z_t|t \equiv E \left[ Z_t | I_{tcb} \right]
\]
General framework
Central bank commits to optimal policy (Svensson Woodford, 2004)

- Case #3: CB minimizes loss

$$\mathcal{L}_0 = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t (\tau_t - \tau_t^*)' W (\tau_t - \tau_t^*) \mid l_t^{cb} \right\}$$

given:
General framework
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given:
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General framework
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given:
- behavior of private sector
- CB observed indicators \( X_s^{cb} \)
Complications due to asymmetry in information of private sector and CB:

- certainty equivalence (pol. same as if eco fully observable): $\implies$ modified (applies only to specific representation of policy)
- separation principle (opt. pol vs signal-extraction): $\implies$ 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

\[
S_t = \bar{Z}_t \equiv \begin{bmatrix}
  Z'_t, \\
  \Xi'_t_{t-1}
\end{bmatrix}'
\]
Equilibrium characterization: Examples

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\]

\[
\bar{Z}_t = \bar{G}_1 \bar{Z}_{t-1} + \bar{u}_t
\]

where

\[
S_t = \bar{Z}_t \equiv [ Z'_t, \Xi'_{t-1} ]'
\]

- Optimal policy (commitment), imperfect information:

\[
\begin{bmatrix}
i_t \\ z_t
\end{bmatrix} = \begin{bmatrix}
0 & \bar{D}_1 \\ \bar{D}_2 & (\bar{D}_2 - \bar{D}_2^\top)
\end{bmatrix} \begin{bmatrix}
\bar{Z}_t
\end{bmatrix}
\]

\[
\begin{bmatrix}
\bar{Z}_{t+1} \\ \bar{Z}_{t+1|t+1}
\end{bmatrix} = \begin{bmatrix}
\bar{G}_1^\top & (\bar{G}_1 - \bar{G}_1^\top) \\ \bar{K} \bar{L} \bar{G}_1^\top & (\bar{G}_1 - \bar{K} \bar{L} \bar{G}_1^\top)
\end{bmatrix} \begin{bmatrix}
\bar{Z}_t \\ \bar{Z}_{t|t}
\end{bmatrix} + H \begin{bmatrix}
\bar{u}_{t+1} \\ \nu_{t+1}
\end{bmatrix}
\]

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, ....
Econometrician: Estimation of states and parameters
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- Special cases:
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- Special cases:
  - No measurement error: \( X_{F,t} = F_t = \Phi S_t \)
Econometrician: Estimation of states and parameters

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

- Special cases:
  - 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 \( \Lambda_S \) 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:

\[ S_t = GS_{t-1} + H\epsilon_t \]

- Observation equation:

\[ X_t = \Lambda S_t + e_t \]

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

- 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. \(\lim_{n\to\infty} \hat{S}_t = S_t\)
2. \(\lim_{n\to\infty} \text{var}(\hat{S}_t) = 0\)

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)
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)
- **IS block**

\[
\tilde{x}_t = E_t \tilde{x}_{t+1} - \varphi^{-1} (\hat{i}_t - E_t \pi_{t+1} - r^n_t)
\]

\[
\tilde{x}_t = (x_t - \eta x_{t-1}) - \beta \eta (E_t x_{t+1} - \eta x_t)
\]

\[
x_t = y_t - y^n_t
\]
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)

- IS block

\[
\tilde{x}_t = E_t \tilde{x}_{t+1} - \varphi^{-1} (\hat{i}_t - E_t \pi_{t+1} - r^n_t)
\]

\[
\tilde{x}_t \equiv (x_t - \eta x_{t-1}) - \beta \eta (E_t x_{t+1} - \eta x_t)
\]

\[
x_t = y_t - y^n_t
\]

- AS block

\[
\pi^w_t - \gamma_w \pi_{t-1} = \xi_w (\omega_w x_t + \varphi \tilde{x}_t) + \xi_w (\omega^n_t - \omega_t)
\]

\[
+ \beta (E_t \pi^w_{t+1} - \gamma_w \pi_t)
\]

\[
\pi_t - \gamma_p \pi_{t-1} = \xi_p \omega_p x_t + \xi_p (\omega_t - \omega^n_t) + \beta (E_t \pi_{t+1} - \gamma_p \pi_t)
\]

\[
\pi^w_t = \pi_t + \omega_t - \omega_{t-1}
\]

\[y^n_t, r^n_t, \omega^n_t: \text{functions of underlying shocks (TFP, gov. exp., labor supply)}\]
Welfare implications in a simple quantitative model

Monetary policy

- Historical monetary policy

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

where \( \pi_t^*, y_t^* \) = indicators observable by CB

\[ \pi_t^* = \pi_t + e_t^\pi \]

\[ y_t^* = y_t + e_t^y \]
Estimation of states

- Observation equation

\[
X_{Ft} = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
0 & 0 & 0 & \lambda_2 \\
0 & 0 & 0 & \lambda_3 \\
0 & 0 & 0 & \lambda_4 \\
\end{bmatrix} 
\begin{bmatrix}
i_t \\
y_t \\
o_t \\
\pi_t \\
\end{bmatrix} + 
\begin{bmatrix}
0 \\
e_t^v \\
e_t^w \\
e_t^{\pi 1} \\
e_t^{\pi 2} \\
e_t^{\pi 3} \\
e_t^{\pi 4} \\
\end{bmatrix}
\]

\[
X_{St} = \Lambda S_t + e_{St}
\]

where \( X_{St} = 35 \) PC of 91 US main macro time series

- 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

<table>
<thead>
<tr>
<th>Structural parameters</th>
<th>&quot;Calibrated&quot; parameters</th>
<th>Persistence of shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta )</td>
<td>0.9900</td>
<td>( \phi_{i1} )</td>
</tr>
<tr>
<td>( \varphi )</td>
<td>3.7719</td>
<td>( \phi_{i2} )</td>
</tr>
<tr>
<td>( \eta )</td>
<td>0.7759</td>
<td>( \phi_\pi )</td>
</tr>
<tr>
<td>( \gamma_p )</td>
<td>0.1506</td>
<td>( \phi_y / 4 )</td>
</tr>
<tr>
<td>( \gamma_\omega )</td>
<td>0.6661</td>
<td></td>
</tr>
<tr>
<td>( \xi_p )</td>
<td>0.0543</td>
<td></td>
</tr>
<tr>
<td>( \xi_\omega )</td>
<td>0.1923</td>
<td></td>
</tr>
<tr>
<td>( \omega_p )</td>
<td>0.6046</td>
<td></td>
</tr>
<tr>
<td>( \omega_w )</td>
<td>0.6718</td>
<td></td>
</tr>
</tbody>
</table>
Welfare loss function

- CB’s welfare-relevant objective function

\[ L_0 = E_0 \left\{ (1 - \beta) \sum_{t=0}^{\infty} \beta^t \left[ \lambda_p (\pi_t - \gamma_p \pi_{t-1})^2 
+ \lambda_w (\pi^w_t - \gamma_w \pi_{t-1})^2 + \lambda_x (x_t - \delta x_{t-1})^2 + \lambda_i i_t^2 \right] \right\} | l_{0cb} \]

- Coefficients:

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_p )</td>
<td>0.596</td>
</tr>
<tr>
<td>( \lambda_w )</td>
<td>0.404</td>
</tr>
<tr>
<td>( 16\lambda_x )</td>
<td>0.800</td>
</tr>
<tr>
<td>( \lambda_i )</td>
<td>0.077</td>
</tr>
<tr>
<td>( \delta )</td>
<td>0.501</td>
</tr>
</tbody>
</table>
Welfare comparisons
Historical policy with alternative information sets

1. CB responds naively to observed indicators $\pi_t^*, y_t^*$

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

not realizing that $\pi_t^*, y_t^*$ are imperfect indicators of $\pi_t, y_t$

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

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

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

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

**Historical policy with alternative information sets**

<table>
<thead>
<tr>
<th>Case</th>
<th>$E[L_0]$</th>
<th>$V[\pi - \gamma_p \pi_{-1}]$</th>
<th>$V[\pi^w - \gamma^w_\pi \pi_{-1}]$</th>
<th>$V[x - \delta x_{-1}]$</th>
<th>$V[i]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>naive</td>
<td>7.70</td>
<td>8.21</td>
<td>4.21</td>
<td>0.85</td>
<td>5.48</td>
</tr>
<tr>
<td>simple filt.</td>
<td>2.74</td>
<td>2.40</td>
<td>1.54</td>
<td>0.71</td>
<td>1.63</td>
</tr>
<tr>
<td>full info.</td>
<td>2.05</td>
<td>1.85</td>
<td>0.95</td>
<td>0.53</td>
<td>1.73</td>
</tr>
<tr>
<td>Case 2/Case 3</td>
<td>1.34</td>
<td>1.30</td>
<td>1.62</td>
<td>1.32</td>
<td>0.94</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>simple filt.</td>
<td>0.98</td>
<td>0.61</td>
<td>0.85</td>
<td>0.21</td>
<td>1.28</td>
</tr>
<tr>
<td>full info.</td>
<td>0.94</td>
<td>0.58</td>
<td>0.75</td>
<td>0.22</td>
<td>1.45</td>
</tr>
<tr>
<td>Case 2/Case 3</td>
<td>1.04</td>
<td>1.04</td>
<td>1.13</td>
<td>0.98</td>
<td>0.88</td>
</tr>
</tbody>
</table>

- 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
Welfare comparisons
Optimal policy with alternative information sets

<table>
<thead>
<tr>
<th>Case</th>
<th>E[L_0]</th>
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<th>V[π^w−γ_w π_{t−1}]</th>
<th>V[x−δ x_{t−1}]</th>
<th>V[i]</th>
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  - Optimal policy more robust to imperfect info about state of economy

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## Welfare comparisons

Optimal policy with alternative information sets

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

Characteze 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 $i_t, \pi_t, y_t$... given available info
- Available indicators give mixed signals
  $\implies$ How to treat multiple signals? What weights?
### Welfare comparisons

Alternative policies and information sets

<table>
<thead>
<tr>
<th>Case</th>
<th>( V[\pi] )</th>
<th>( V[\pi^w] )</th>
<th>( V[y] )</th>
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</thead>
<tbody>
<tr>
<td><strong>Historical policy</strong></td>
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<tr>
<td>1 naive</td>
<td>10.81</td>
<td>11.74</td>
<td>4.86</td>
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<tr>
<td>2 simple filt.</td>
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<td>2.64</td>
<td>3.59</td>
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<tr>
<td>3 full info.</td>
<td>2.26</td>
<td>1.60</td>
<td>3.86</td>
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<tr>
<td>Case 2/Case 3</td>
<td>1.31</td>
<td>1.65</td>
<td>0.93</td>
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<tr>
<td><strong>Optimal policy</strong></td>
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<td></td>
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</tr>
<tr>
<td>4 simple filt.</td>
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<td>0.49</td>
<td>6.29</td>
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<tr>
<td>5 full info.</td>
<td>0.68</td>
<td>0.32</td>
<td>6.32</td>
</tr>
<tr>
<td>Case 4/Case 5</td>
<td>1.05</td>
<td>1.54</td>
<td>0.99</td>
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“Estimation” of structural parameters: A short-cut

<table>
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<th>St. dev. of shocks estimated with large data set</th>
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<tbody>
<tr>
<td>( \sigma_a )</td>
<td>1.4995</td>
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<tr>
<td>( \sigma_g )</td>
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<tr>
<td>( \sigma_h )</td>
<td>0.9768</td>
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<tr>
<td>( \sigma_{\varepsilon i} )</td>
<td>0.2589</td>
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<tr>
<td>( \sigma_{e\pi} )</td>
<td>0.1880</td>
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<tr>
<td>( \sigma_{ey} )</td>
<td>0.0222</td>
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