# Bank of Thailand DSGE Model

**Presented at the Workshop on**

## ECONOMIC MODELS AT THE BANK OF THAILAND

**Organized by the**

**Modelling and Forecasting Team**

**December 17, 2008**

# Presentation Outline

1. Motivation
2. The Model
3. Model parameterization
4. Model properties
5. Model evaluation
6. Conclusions

# 1. Motivation

# 1.1. Purpose (1)

**Wanted: A fully integrated framework for policy analysis**

**A model that**

- **Has a strong theoretical foundation and relates to structural features of the economy**
- **Tells a coherent story**
- **Answers policy questions**
- **Provides forecasts on a regular basis**

# 1.1. Purpose (2)

**Current stage of a structural model currently developed at BOT**

- ✓ Having a sufficiently rich micro foundation
- ✓ Capturing structural features of the Thai economy
- ✓ Giving internally consistent stories under various simulations
- ✓ Answering policy questions qualitatively
- ■ Answering policy questions quantitatively
- ■ Forecasting

# 1.2. Macroeconometric and DSGE Models

| Model property | Macroeconometric Models | DSGE Models |
|---|---|---|
| ■ Dynamic | Yes | Yes |
| ■ Stochastic | Unexplained variations in the endogenous variables are regression residuals | Unexplained variations in the endogenous variables are random shocks with well-defined distribution |
| ■ General Equilibrium | Relationships are loosely based on theory in ad hoc manner | Relationships are explicitly based on optimization in coherent manner |

# 2. The Model

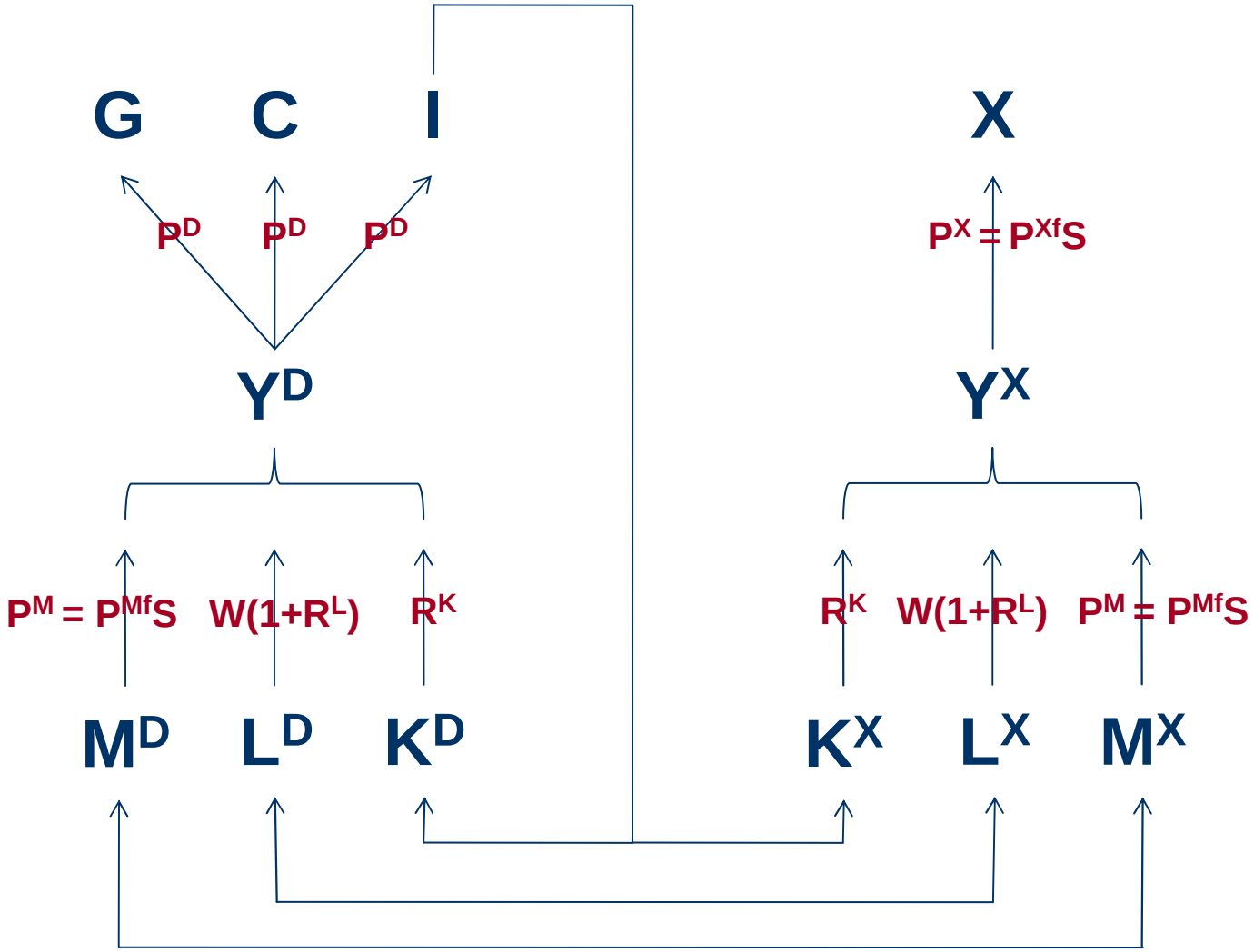
# 2.1. Model Requirements for the Thai Economy

- **Mimic the structure of the economy**
  - **Small open economy (emphasis on the external sector)**
- **Match observed features of the economy**
  - ***Long-term features***
    - **Productivity growth**
    - **GDP component and factor income shares**
  - ***Short-term features***
    - **Rigidities in wage and prices**

# 2.2. Model Environment

| Agents | What they do | Features |
|---|---|---|
| Households | ■Consume and invest | ■Consumption habit persistence; Investment adjustment costs |
| | ■Deposit funds with banks; trade foreign bonds | ■Debt-contingent premium on foreign borrowing |
| | ■Supply labor to firms and set wage | ■Monopolistic supplier of differentiated labor; wage rigidities |
| Export Firms | ■Hire inputs and produce | ■Competitive supplier of export good; no rigidity in export price |
| Domestic Firms | ■Only domestic firms set output price and borrow from banks to pay for labor | ■Monopolistic supplier of domestic good; domestic price rigidities |
| Banks | ■Take deposits from households and lend to domestic firms | ■Competitive supplier of loans; financial frictions |
| Government | ■Spend according to some rule | ■Ricardian equivalence |
| Central Bank | ■Set interest rate according to some rule | ■Inflation targeting with interest rate smoothing |

# 2.3. Model Structure




## DEMAND

Domestic demand

- Consumption (C)
- Investment (I)
- Govt spending (G)

External demand

- Exports (X)

## OUTPUTS

- Domestic good ($Y^D$)
- Export good ($Y^X$)

## INPUTS

- Capital ($K^D$, $K^X$)
- Labor ($L^D$, $L^X$)
- Import ($M^D$, $M^X$)

# 2.4. Model Equations (1)

## Model consists of

- First-order conditions and policy rules
- Exogenous processes
- Market clearing conditions
- Steady-state conditions

Fully/partially micro-founded behavior

Transition dynamics

N equations for N unknowns

Transition dynamics plus terminal conditions

Dynamic path of model variables can be solved (Think of solving a system of differential equations)

# 2.4. Model Equations (2)

## 2.4.1. First-order conditions

### Ex. 1. Households

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ (1-\chi) \log \tilde{C}_t - \varphi^L \frac{L_t^{1+\eta}}{1+\eta} \right]$$

subject to

$$P_t^D (C_t + I_t) + D_t \leq (1 + R_{t-1}) D_{t-1} + W_t L_t + R_t^K K_t + \textstyle\sum_j \Phi_j$$
$$K_{t+1} \leq (1-\delta) K_t + F(I_t, I_{t-1}).$$

# 2.4. Model Equations (3)

**Consumption habit persistence**

$$\tilde{C}_t = \frac{C_t - \chi h_t}{1 - \chi} \quad \text{with} \quad h_t = (1 + \alpha) C_{t-1}$$

**Not today's consumption that matters, but how it is compared with "habit"**

**Optimal consumption**

$$\frac{1}{\tilde{C}_t} = \lambda_t P_t^D$$

***Intuition*** **Utility gained from consuming one unit more (LHS) equals utility lost from having wealth reduced (RHS)**

# 2.4. Model Equations (4)

**Investment adjustment costs**

$$K_{t+1} = (1-\delta)K_t + F(I_t, I_{t-1})$$

$$F(I_t, I_{t-1}) = \left[1 - \frac{\xi^I}{2}\left(\frac{I_t}{I_{t-1}} - (1+\alpha)\right)^2\right] I_t$$

**Capital accumulated throughout this period is not equal to today's investment, but is instead a function of investment made today and yesterday**

# 2.4. Model Equations (5)

## Optimal investment

$$\frac{Q_t^K}{P_t^D} = \frac{1}{1 - \xi^I \frac{I_t}{I_{t-1}} \left[\frac{I_t}{I_{t-1}} - (1+\alpha)\right] - \frac{\xi^I}{2}\left[\frac{I_t}{I_{t-1}} - (1+\alpha)\right]^2} \times \left[1 - \xi^I \beta \mathrm{E}_t \frac{\lambda_{t+1}}{\lambda_t} \frac{Q_{t+1}^K}{P_t^D} \left(\frac{I_{t+1}}{I_t}\right)^2 \left[\frac{I_{t+1}}{I_t} - (1+\alpha)\right]\right]$$

***Intuition***

- LHS is Tobin's *q*, which is the ratio of the shadow value of capital to the replacement cost of capital
- When $\xi^I = 0$ the equilibrium condition is given by $q = 1$
- There will be more (less) investment if *q* is greater (less) than unity

# 2.4. Model Equations (6)

**Exchange rate determination**

$$\max_{B_t^*} \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_t S_t \left\{ B_t^* - \left[ 1 + \frac{\xi^B}{2} \left( \frac{S_{t-1} B_{t-1}^*}{4 Y_{t-1}^N} - \psi \right) \right] \left( 1 + R_{t-1}^* \right) B_{t-1}^* \right\}$$

**First-order condition:**

$$R_t - R_t^* = \mathrm{E}_t dS_{t+1} + \xi^B \left( \frac{B_t}{4 Y_t^N} - \frac{\psi}{2} \right) + \upsilon$$

***Intuition***

- The term in the square brackets is the premium on the rate at which the household can borrow, and this premium is increasing in the ratio of debt to nominal GDP
- First-order condition with respect to $B_t^*$ gives a UIP condition

# 2.4. Model Equations (7)

## Ex. 2. Domestic firms

### Cost minimization

$$\mathcal{L}^D = \left(1 + R_t^L\right) W_t L_t^D + P_t^M M_t^D + R_t^K K_t^D + Q_t^D \left[ Y_t^D - \left(A_t L_t^D\right)^{\gamma_L^D} \left(M_t^D\right)^{\gamma_M^D} \left(K_t^D\right)^{1-\gamma_L^D-\gamma_M^D} \right]$$

### Optimal inputs demanded

$$\begin{aligned} \left(1 + R_t^L\right) W_t L_t^D &= \gamma_L^D Q_t^D Y_t^D \\ P_t^M M_t^D &= \gamma_M^D Q_t^D Y_t^D \\ R_t^K K_t^D &= \left(1 - \gamma_L^D - \gamma_M^D\right) Q_t^D Y_t^D \end{aligned}$$

# 2.4. Model Equations (8)

**Pricing problem**

$$\min_{P_t^D} \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ (P_t^D - P_t^{D*})^2 + \xi^D (\Delta P_t^D - \Delta \bar{P}_{t-1}^D)^2 \right]$$

**Optimal price setting**

$$P_t^D = P_t^{D*} + \xi^D \left[ - \left( \Delta P_t^D - \Delta \bar{P}_{t-1}^D \right) + \beta \left( \mathrm{E}_t \Delta P_{t+1}^D - \Delta \bar{P}_t^D \right) \right]$$

where $P_t^{D*} = \mu^D Q_t^D$.

# 2.4. Model Equations (9)

## 2.4.2. Exogenous processes

**Productivity** $$A_t = A_{t-1} + \alpha + \varepsilon_t^A$$

***Intuition*** **Productivity growth is a random walk with drift**

## 2.4.3. Market clearing conditions

**Capital at any *t*** $$K_t = K_t^D + K_t^X$$

***Intuition*** **Capital supplied by households = capital demanded by firms**

## 2.4.4. Steady-state conditions

**Capital in steady state** $$K_t^{ss} = \bar{K} + \alpha t$$

***Intuition*** **Along balanced growth path capital-output share is constant**

# 3. Model Parameterization

**Two broad methods for parameterizing DSGE models: estimation and calibration**

- **Estimation** Potential difficulties with the likelihood: limited data, structural breaks, flat regions, discontinuities, or multiple local maxima
- **Calibration** Select parameters based on empirical findings that result in model that best characterizes Thai economy

# 3.1. Steady-State Parameters

| Parameter | Value | Description |
|---|---|---|
| Households | | |
| $\beta$ | 0.9926 | Discount factor (real interest rate 3% per year) |
| $\delta$ | 0.0105 | Depreciation rate (4.2% per year) |
| $\eta$ | 3.0303 | Inverse of Frisch elasticity |
| $\varphi^L$ | 1 | Scaling parameter for labor disutility |
| $\mu^W$ | 1.05 | Wage markup |
| $\psi$ | 0.25 | Ratio of foreign debt to nominal GDP |
| Firms | | |
| $\mu^D$ | 1.20 | Price markup, domestic firms |
| $\gamma_L^D$ | 0.70 | Labor income share, domestic firms |
| $\gamma_M^D$ | 0.15 | Imported input income share, domestic firms |
| $\gamma_L^X$ | 0.64 | Labor income share, export firms |
| $\gamma_M^X$ | 0.18 | Imported input income share, export firms |
| Government | | |
| $\sigma$ | 0.20 | Ratio of govt. expenditure to nominal GDP |
| $\pi$ | 0.0074 | Inflation target (3% per year) |
| Exogenous processes | | |
| $\alpha$ | 0.0059 | Productivity growth rate (2.4% per year) |
| $\pi^*$ | 0.0074 | Foreign inflation target (3% per year) |

# 3.2. Dynamic Parameters

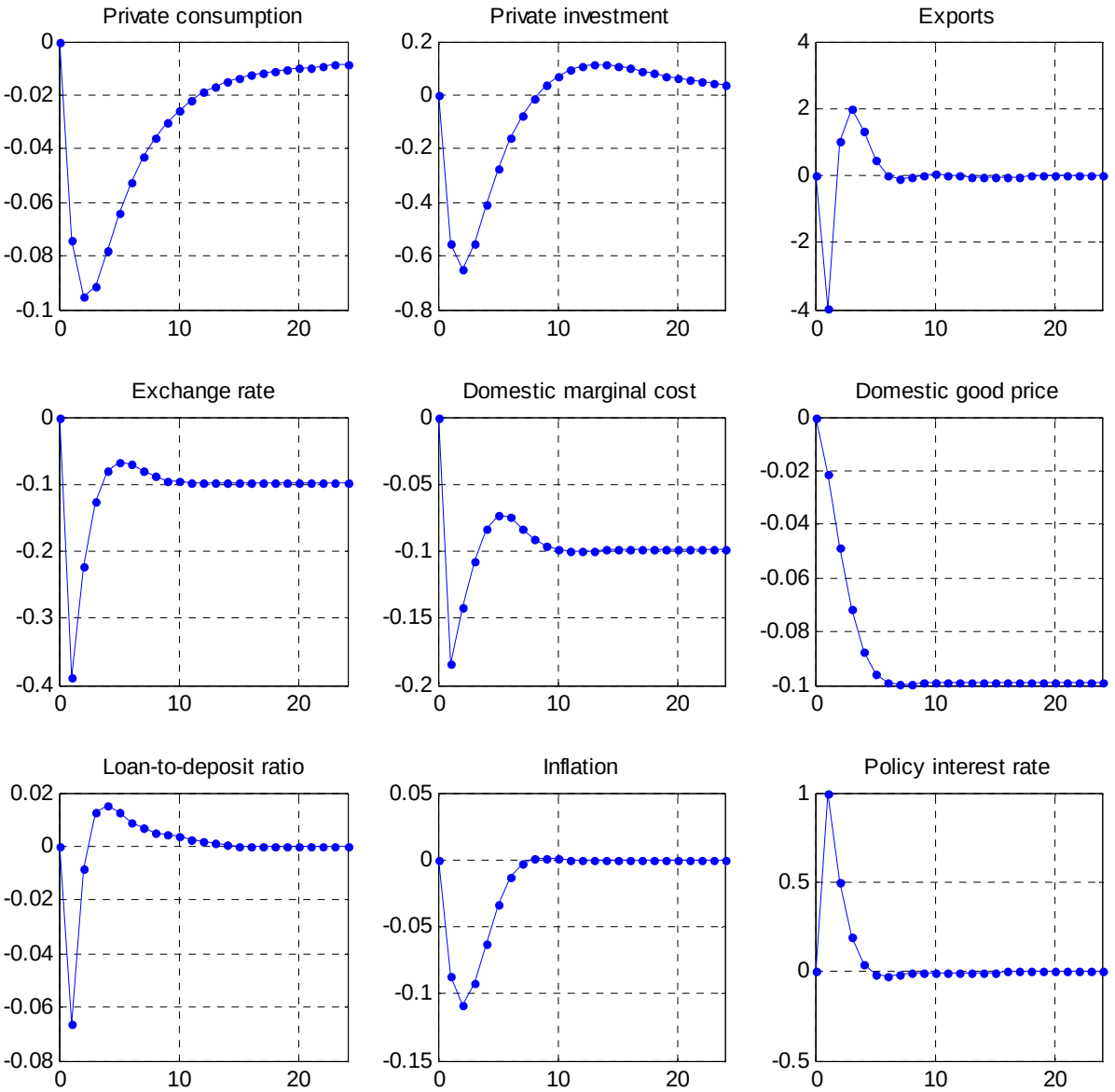
| Parameter | Value | Description |
|---|---|---|
| Households | | |
| $\chi$ | 0.85 | Consumption habit persistence |
| $\xi^I$ | 1 | Investment adjustment cost |
| $\xi^W$ | 10 | Wage adjustment cost |
| $\xi^B$ | 0.4 | Interest rate premium on foreign debt holdings |
| $\upsilon$ | 0.005 | Differential between domestic and foreign interest rate |
| Firms | | |
| $\xi^D$ | 10 | Degree of price rigidities |
| Banks | | |
| $\tau$ | 0.5 | Elasticity of willingness to lend with respect to domestic output growth |
| Government | | |
| $\rho^G$ | 0.80 | Persistence in government expenditure |
| $\rho^R$ | 0.85 | Persistence in policy interest rate |
| $\kappa$ | 25 | Responsiveness of policy rate to inflation |
| Exogenous processes | | |
| $\rho^{R^*}$ | 0.8 | Persistence in foreign interest rate |
| $\rho^T$ | 0.8 | Persistence in terms of trade |

# 4. Model Properties

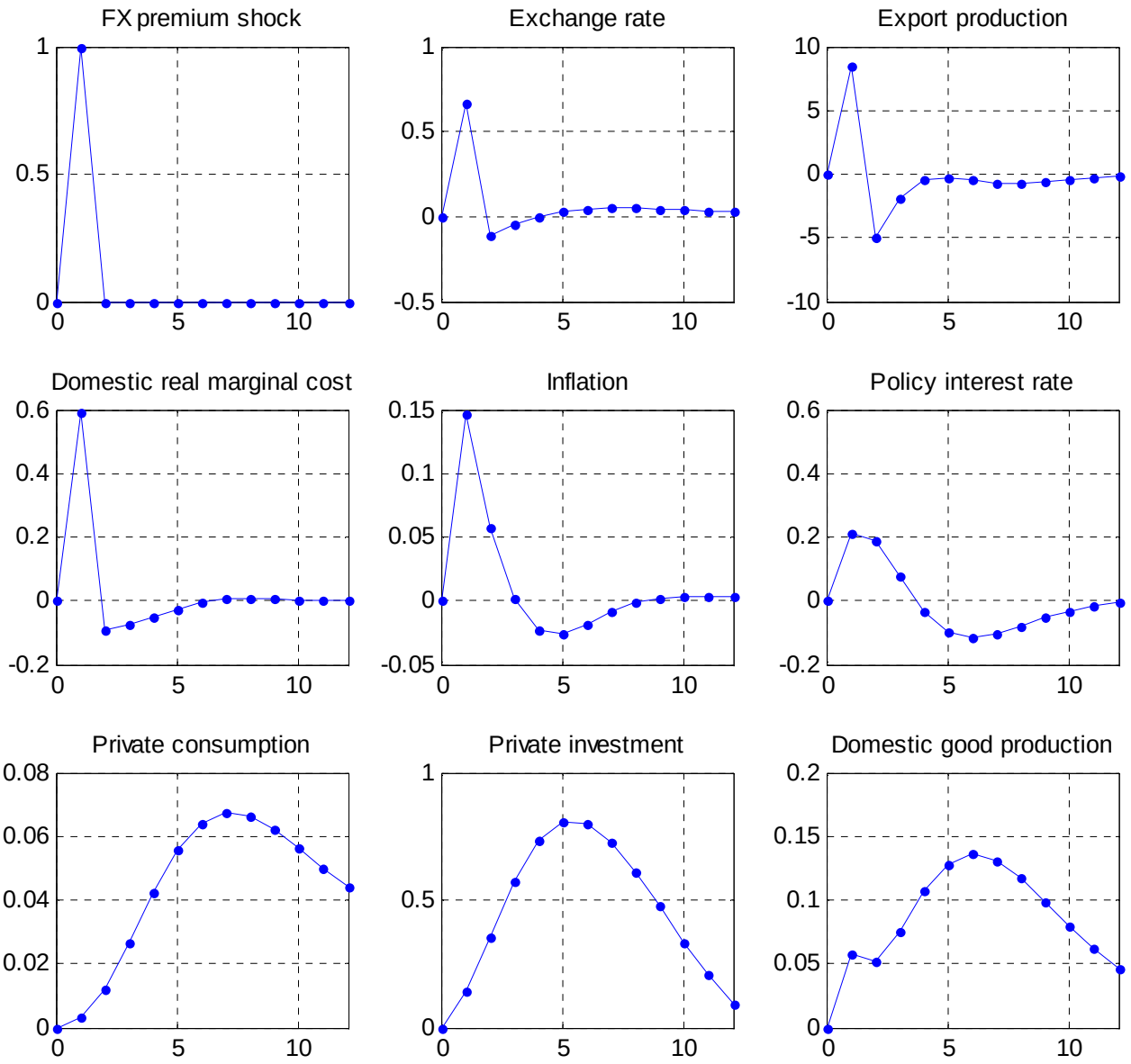
## Simulation

- Start from the steady state
- Perturb the model by introducing shocks
- Solve for transition paths toward the post-shock steady state

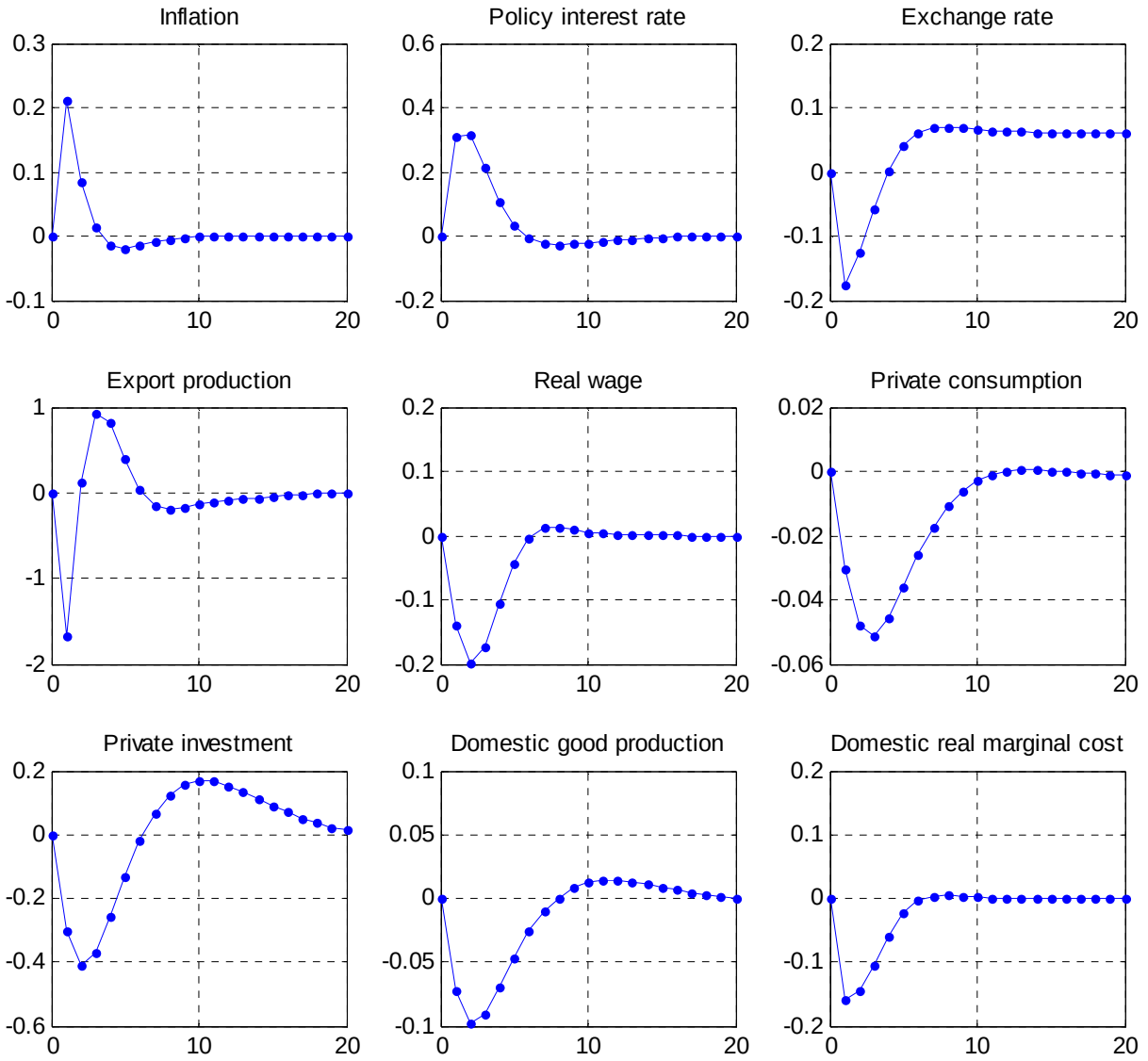
# Interest Rate Shock



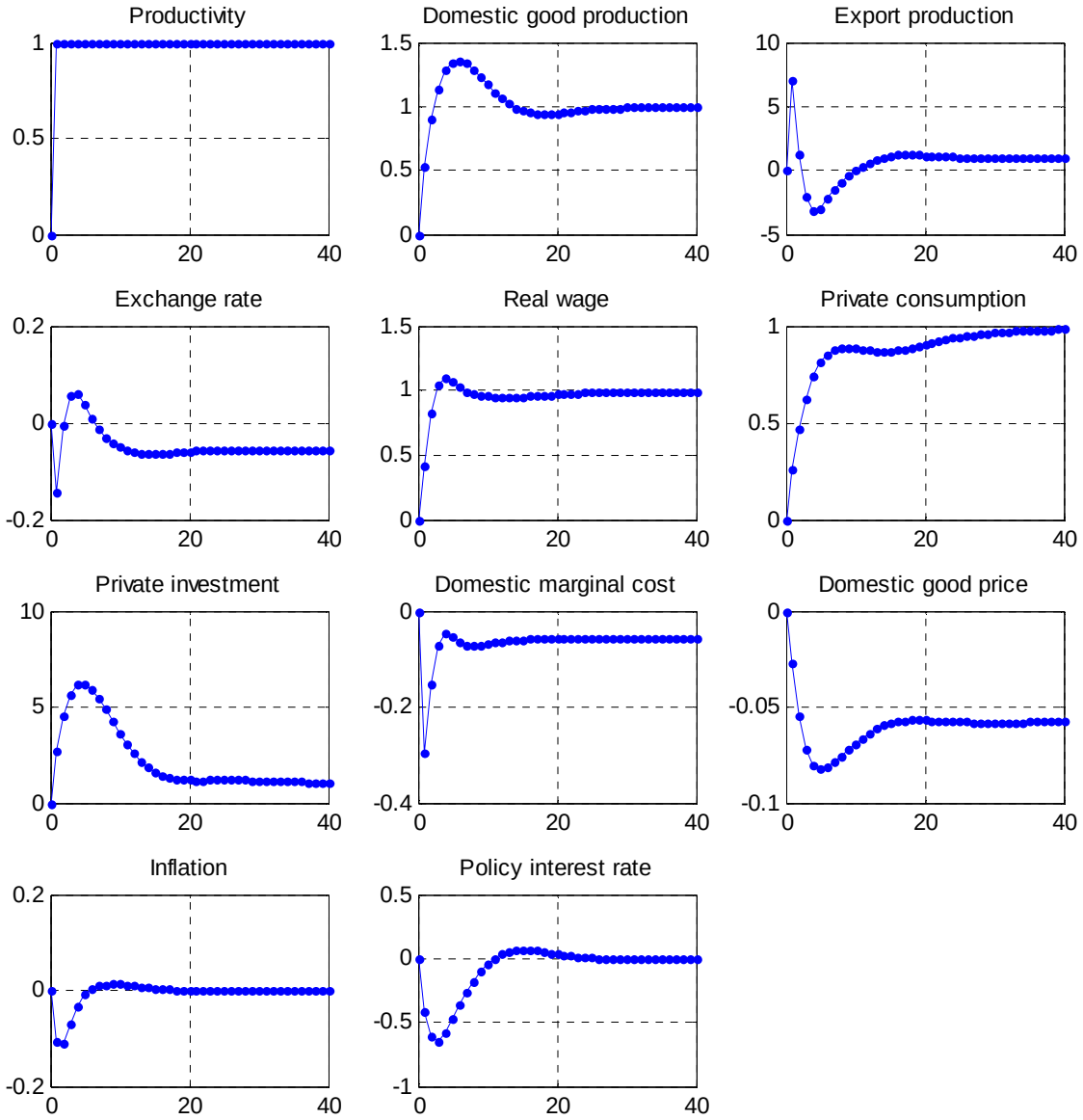
# Exchange Rate Shock



# Price Shock


Inflation
0.3
0.2
0.1
0
-0.1
0
10
20
Policy interest rate
0.6
0.4
0.2
0
-0.2
0
10
20
Exchange rate
0.2
0.1
0
-0.1
-0.2
0
10
20
Export production
1
0
-1
-2
0
10
20
Real wage
0.2
0.1
0
-0.1
-0.2
0
10
20
Private consumption
0.02
0
-0.02
-0.04
-0.06
0
10
20
Private investment
0.2
0
-0.2
-0.4
-0.6
0
10
20
Domestic good production
0.1
0.05
0
-0.05
-0.1
0
10
20
Domestic real marginal cost
0.2
0.1
0
-0.1
-0.2
0
10
20

# Productivity Shock



# 5. Model Evaluation

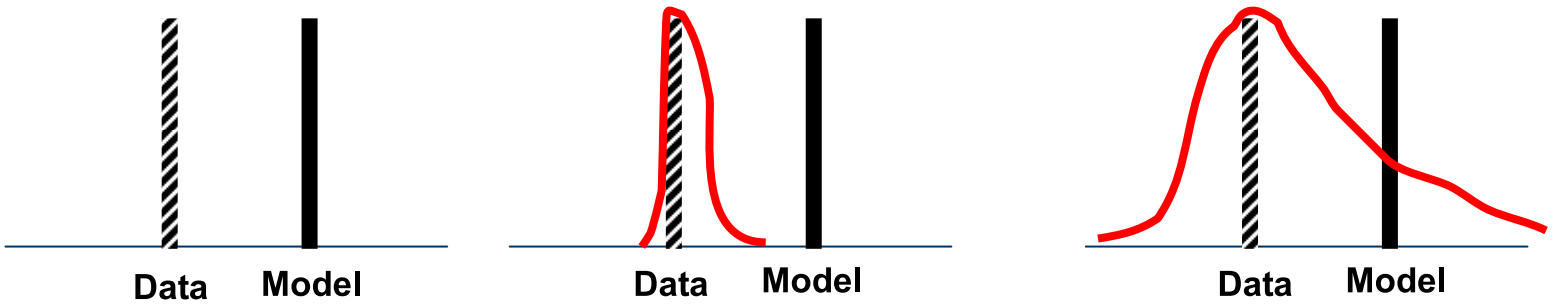
## Evaluation

- Model not to be judged primarily by how well it fits data
- But also by how well it captures key aspects of monetary policy transmission mechanism

# 5. Model Evaluation

## Methodology (1)

- Compare statistical moments (volatility, persistence, comovements) obtained from model vs. data
- Moments implied by model can be computed in straightforward manner
- Moments implied by data
  - Sample moments: Kydland and Prescott (1982)
  - Distribution of moments: Benes, de Castello Branco, and Vavra (2007)



# 5. Model Evaluation

## Methodology (2)

- Calculate the point estimate of the empirical population moment—say, autocorrelation—by fitting a VAR

$$\mathbf{x}_t = A\mathbf{x}_{t-k} + \varepsilon_t$$

- Resample $x_t$ using a bootstrap procedure

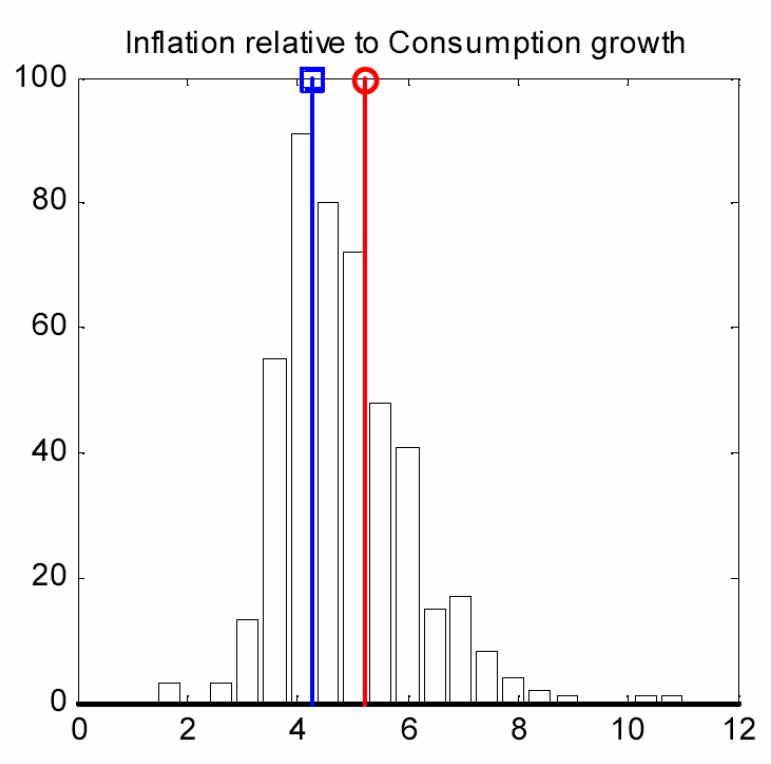
$$\hat{\mathbf{x}}_t^i = A\hat{\mathbf{x}}_{t-k}^i + \eta^i \varepsilon_t$$

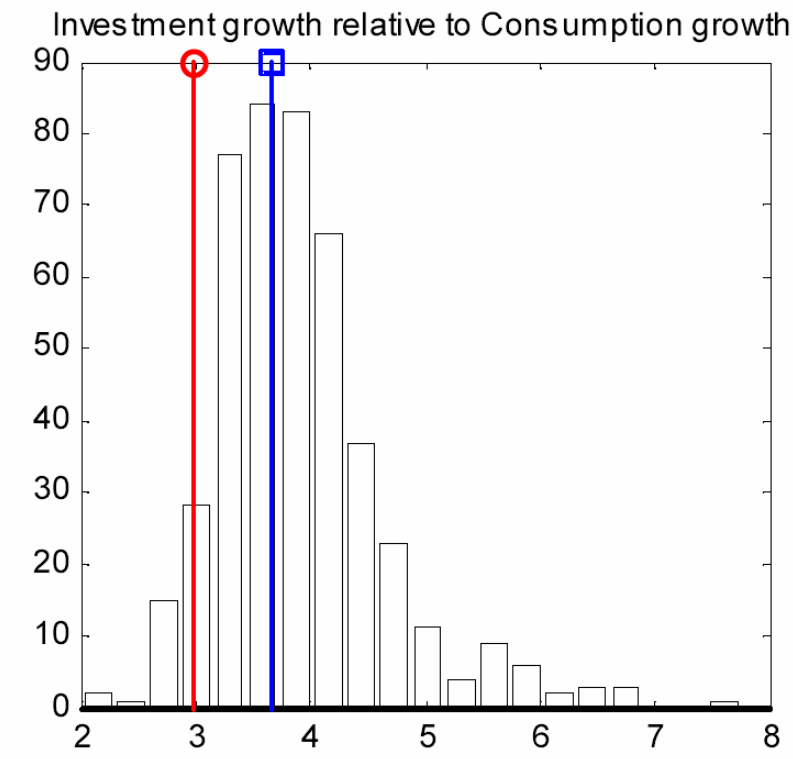
- Given $\hat{\mathbf{x}}_t^i$ we reestimate a VAR

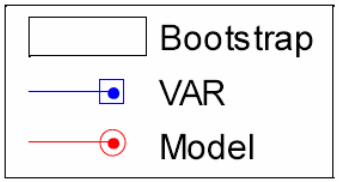
$$\hat{\mathbf{x}}_t^i = \hat{A}^i \hat{\mathbf{x}}_{t-k}^i + \hat{\varepsilon}_t^i$$

For each $i$th resampling we now have $\hat{A}^i$ and $\hat{\varepsilon}_t^i$ as respective counterparts to $A$ and $\varepsilon_t$ of the first step. Consequently, we can compute the autocorrelation function for the $i$th resampling, which is a function of $var\left(\hat{\varepsilon}_t^i\right)$ and $\hat{A}^i$, leading to a distribution of the autocorrelation.

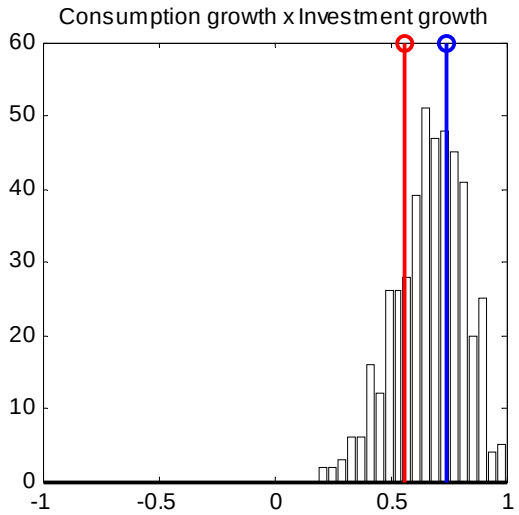
# Relative Standard Deviations

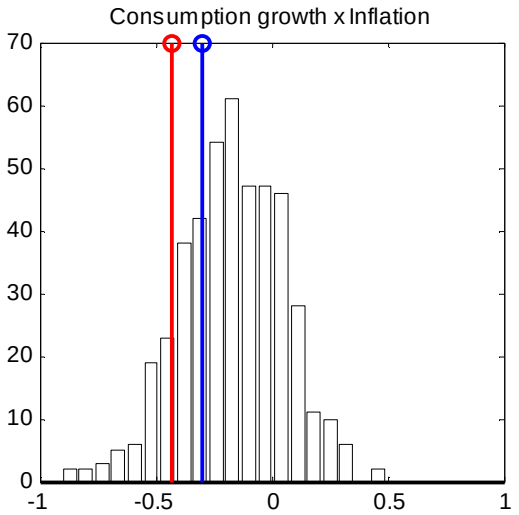


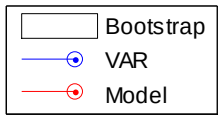



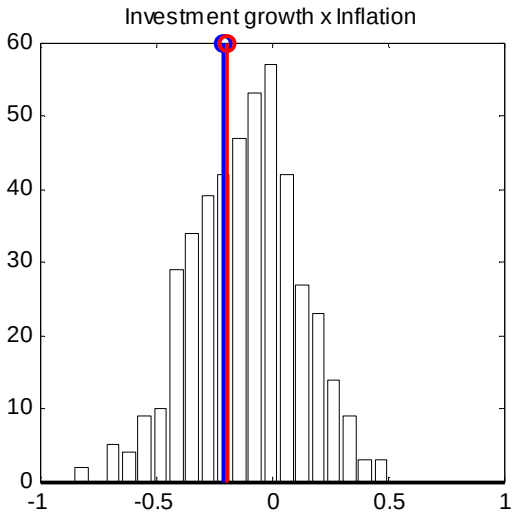



# Cross Correlations



# 6. Conclusions: What have we done

## Important model features

- Optimizing agents make intertemporal decisions rationally
- Nominal and real frictions incorporated to generate realistic dynamics
- Parameters are calibrated based on empirical findings
- We assess model properties by examining impulse responses which are found to be mostly reasonable
- We also assess statistical moments implied by the model and compare them with those obtained from the data. Certain moments are better matched with data than others

# 6. Conclusions: Plans ahead

## Several model development plans are currently under way

- **Model structure**
  - Introduce consumption of import good
  - Move away from the competitive banking sector
  - Revisit the fiscal rule to prepare for larger role of fiscal policy
- **Parameterization**

  Estimate the model formally using the Bayesian approach
  - Allow the data to determine model parameters in a more consistent manner, while we can still incorporate our prior beliefs in the form of calibrated values

# Epilogue

- Experience over the past two years has proved that knowledge sharing among central bank staff has been a success
- While DSGE models are widely considered the workhorse model for policy analysis that is at the research frontier
  - It needs to be kept in mind that no single model can answer all types of questions correctly all the time
- What is more important is a good understanding of the inner workings of the economy, which are essentially what every economic model tries to capture and every economist tries to appreciate