

# **A Comparison of Forecast Performance Between Federal Reserve Staff Forecasts, Simple Reduced-Form Models, and a DSGE Model**

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## **Broader Research Agenda:**

- To develop an estimated DSGE model that can be used in policy work (such as, alternative forecast generation, interpretation of incoming data, and analysis of monetary policy questions).
  - This model is intended to serve as a compliment to the FRB/US model.

## **This paper:**

- Uses a DSGE model that we developed in earlier work (Edge, Kiley, and Laforte, 2006) to generate a set of real-time forecasts.
- Compares real-time forecasts generated by our DSGE model to:
  - Greenbook projections; and,
  - Real-time forecasts implied by alternative atheoretic models.

## Outline of the Presentation

- Motivate why a central bank may want a DSGE model in its suite of models.
- Sketch-out our multi-sector production and expenditure DSGE model.
  - Emphasize the features of the model that differ from the canonical Christiano-Eichenbaum-Evans/Smets-Wouters models; and,
- Describe the real-time environment, the Greenbook, and the competing forecasting models;
- Comparison of the Greenbook and the models' forecasts since September 1996;
- Sum up.

## Why use a DSGE model in the forecast and policy process?

- DSGE models are useful instruments for “storytelling;” and,
- In policy environments storytelling is a necessary complement to quantitative analysis.

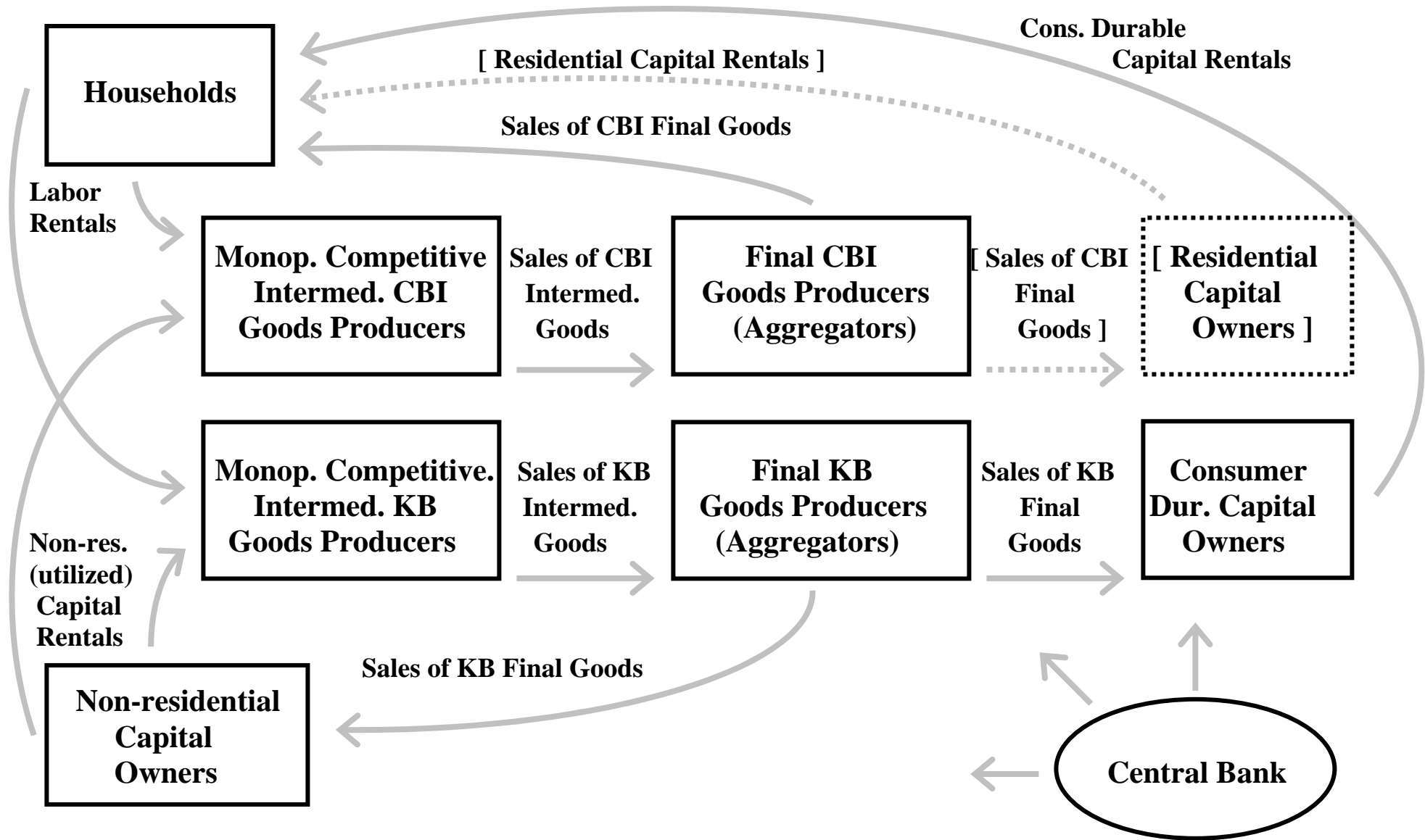
*“A model-based forecast ends with a story... My experience as a commercial forecaster taught me that clients did not want to be buried in computer output. They demanded a coherent story that tied the forecast together.” Laurence H. Meyer (1997)*

*“As a policymaker... I find a great value in the story behind a forecast, even if I suspect that unforeseen events could prove the forecast wrong.” Sandra Pianalto (2006)*

## Model Overview

The model is more disaggregated than most closed economy models.

- The model has two business and institutions production sectors:
  - A slow-growing “consumption” goods producing sector,  $X^{cbi}$ ;  
and,
  - A fast-growing “capital” goods producing sector,  $X^{kb}$ .
- The model has multiple expenditure aggregates:
  - Expenditures on consumer non-durable goods and services,  $E^{cnn}$ ;
  - Expenditures on consumer durable goods,  $E^{cd}$ ;
  - [ Expenditures on residential capital,  $E^r$ ; ] and,
  - Expenditures on non-residential capital,  $E^{nr}$ .



## Model Overview: Why do we disaggregate the production sector?

- U.S. NIPA data are *not* consistent with a one-sector Solow-Ramsey model. There are:
  - Sizable differences in long-run average real growth rates across expenditure categories; and,
  - Large trends in relative prices (as well different cyclical properties).
- U.S. NIPA data are better approximated by a two-sector model with a steady-state balanced *nominal* growth path.
  - Nominal growth rates are broadly similar across expenditure categories.

## Average Growth and Relative Price Changes (1984q1 to 2004q4)

|  | Avg. Real Growth       | Avg. Nom. Growth       | Avg. Price Change       |
|--|------------------------|------------------------|-------------------------|
| Cons. non-durables & services, $E^{cnn}$ | $3\frac{1}{4}$ percent | $6\frac{1}{4}$ percent | n.a.                    |
| Cons. durables, $E^{cd}$                 | $6\frac{3}{4}$ percent | $6\frac{1}{2}$ percent | -3 percent              |
| [ Res. investment, $E^r$                 | $3\frac{3}{4}$ percent | $7\frac{1}{2}$ percent | $\frac{1}{2}$ percent ] |
| Non-res. investment, $E^{nr}$            | $6\frac{1}{4}$ percent | $6\frac{1}{4}$ percent | $-2\frac{3}{4}$ percent |

- $E^{cnn}$  [ and  $E^r$  ] are purchased from the slow-growing sector  $X^{cbi}$ .
- $E^{cd}$  and  $E^{nr}$  are purchased from the fast-growing sector  $X^{kb}$ .

## Model Overview: Why do we further disaggregate expenditures?

- Different expenditure categories have different cyclical properties.
  - Consumer durables [ and residential investment ] tend to lead business cycles, while non-residential *fixed* investment tends to lag.
  - Consumer durables [ and residential investment ] may be more responsive to monetary policy.
- Policy-makers are concerned with movements in detailed aggregates.
  - See Kohn (2003) “The Strength in Consumer Durables and Housing: Policy Stabilization or a Problem in the Making.”
- Growth accounting requires that the (latent) capital stock series used in the model’s production functions correspond to conventional definitions of productive capital.

## Model Overview

Nominal rigidities:

- Sticky prices and sticky wages, where both lagged inflation and steady-state inflation determine adjustment costs.

Real rigidities:

- Habit-formation in consumption;
- Adjustment costs to investment; and,
- Adjustment costs to cross-sectoral factor movements; and,
- Variable utilization of non-residential capital.

The model has 14 structural shocks; 9 display persistence.

## Balanced Nominal Growth and Production

The intermediate goods sectors' production functions are:

$$X_t^{cbi} = (K_t^{cbi})^\alpha (Z_t^m L_t^{cbi})^{1-\alpha} \quad \& \quad X_t^{kb} = (K_t^{kb})^\alpha (Z_t^m Z_t^{kb} L_t^{kb})^{1-\alpha}$$

The technology variables in the intermediate-goods sectors follow

$$\ln(Z_t^s / Z_{t-1}^s) = \ln \Gamma_t^{z,s} = \ln \Gamma_*^{z,s} + \gamma_t^{z,s} \quad \text{where} \quad \gamma_t^{z,s} = \rho^{z,s} \gamma_{t-1}^{z,s} + \epsilon_t^{z,s}, \quad s = m, k.$$

| Sector | Real Gr. ( $\Gamma_*^{x,s}$ )             | Inflation ( $\Pi_*^{p,s}$ )                  | Nom. Gr. ( $\Gamma_*^{x,s} \Pi_*^{p,s}$ )               |
|--------|---|--|---|
| Slow   | $\Gamma_*^{z,m} (\Gamma_*^{z,kb})^\alpha$ | $\Pi_*^{p,cbi}$                              | $\Pi_*^{p,cbi} \Gamma_*^{z,m} (\Gamma_*^{z,kb})^\alpha$ |
| Fast   | $\Gamma_*^{z,m} \Gamma_*^{z,kb}$          | $\Pi_*^{p,cbi} (\Gamma_*^{z,kb})^{\alpha-1}$ | $\Pi_*^{p,cbi} \Gamma_*^{z,m} (\Gamma_*^{z,kb})^\alpha$ |

## Household Preferences

- Utility is defined over leisure and the following goods:
  - Consumer non-durable goods and services,  $E_t^{cnn}$ ;
  - Consumer durable capital stock,  $K_t^{cd}$ , and
  - [ Residential capital stock,  $K_t^r$ . ]
- Within-period utility is:

$$\begin{aligned} & \varsigma^{cnn} \Xi_t^{cnn} \ln \left( E_t^{cnn}(i) - h^{cnn} E_{t-1}^{cnn}(i) \right) + \varsigma^{cd} \Xi_t^{cd} \ln \left( K_t^{cd}(i) - h^{cd} K_{t-1}^{cd}(i) \right) \\ & \quad \left[ + \varsigma^r \Xi_t^r \ln \left( K_t^r(i) - h^r K_{t-1}^r(i) \right) \right] - \varsigma^l \Xi_t^l \frac{\left( L_t^{cbi}(i) + L_t^{kb}(i) \right)^{1+\nu}}{1+\nu}. \end{aligned}$$

- $\Xi_t^{cnn}$ ,  $\Xi_t^{cd}$ , [  $\Xi_t^r$ , ] and  $\Xi_t^l$ , are persistent preference shocks.
- Issue: Double counting of housing services.

## Capital Evolution Processes

- The economy possesses multiple capital stocks:
  - Non-residential capital,  $K_t^{nr}$ ;
  - [ Residential capital stock,  $K_t^r$ ; ] and,
  - Consumer durable capital stock,  $K_t^{cd}$ .
- Investment incurs adjustment costs; e.g., non-res. capital evolves:

$$K_{t+1}^{nr}(k) = (1 - \delta^{nr})K_t^{nr}(k) + A_t^{nr} E_t^{nr}(k) - \frac{100 \cdot \chi^{nr}}{2} \left( \frac{E_t^{nr}(k) - \eta^{nr} E_{t-1}^{nr}(k) \Gamma_t^{y,kb} - (1 - \eta^{nr}) \tilde{E}_*^{nr} Z_t^m Z_t^{kb}}{K_t^{nr}} \right)^2 K_t^{nr}$$

- $A_t^{nr}$  is a transitory, but persistent, capital “efficiency” shock.
- [ Residential and ] consumer durables capital evolve similarly.

## Nominal Rigidities

- Intermediate goods producing firms and households face convex adjustment costs in altering their prices and nominal wages.
- Adjustment costs depend on both lagged and steady-state inflation.
- The log-linearized price Phillips curves are:

$$\pi_t^{p,s} = \frac{\eta^{p,s}}{1 + \beta\eta^{p,s}} \cdot \pi_{t-1}^{p,s} + \frac{\beta}{1 + \beta\eta^{p,s}} \cdot E_t \pi_{t+1}^{p,s} - \frac{1}{1 + \beta\eta^{p,s}} \cdot \frac{1}{100 \cdot \chi^{p,s} (\Pi_*^{p,s})^2} \left( (\Theta_*^{y,s} - 1) mc_t^s - \theta_t^{y,s} \right).$$

- In this paper, we assume that price adjustment costs are the same in both sectors, *i.e.*  $\chi^{p,cbi} = \chi^{p,kb}$ .
- The log-linearized wage Phillips curves take a similar form.

# Monetary Policy

- The log-linearized monetary policy rule is:

$$r_t = \phi^r \cdot r_{t-1} + (1 - \phi^r) \cdot \bar{r}_t + \epsilon_t^r$$

where

$$\begin{aligned} \bar{r}_t = & \phi^{\pi, gdp} \cdot \pi_t^{p, gdp} + \phi^{\Delta\pi, gdp} \cdot \Delta\pi_t^{p, gdp} \\ & + \phi^{h, gdp} \cdot h_t^{gdp} + \phi^{\Delta h, gdp} \cdot \Delta h_t^{gdp}. \end{aligned}$$

$$\pi_t^{p, gdp} = \text{GDP Price Inflation}$$

$$h_t^{gdp} = \text{Real GDP Growth}$$

## Real GDP Growth

- Real GDP growth,  $H_t^{gdp}$ , is a Tornquist index.
- This is defined as a weighted average of the real growth rates of the economy's three final outputs:
  - $X_t^{cbi}$ : produced in “slow” sector, purchased for  $E_t^{cnn}$  [ and  $E_t^r$  ];
  - $X_t^{kb}$ : produced in “fast” sector, purchased for  $E_t^{cd}$  and  $E_t^{nr}$ ;
  - $X_t^{gf}$ : exogenous production, which meets government and foreign demand.
- These weights are an average of each outputs' share of total nominal output in the current and previous period.
- *Normalized* exogenous production follows the process:

$$\ln \tilde{X}_t^{gf} - \ln \tilde{X}_*^{gf} = \rho^{x,gf} \left( \ln \tilde{X}_{t-1}^{gf} - \ln \tilde{X}_*^{gf} \right) + \epsilon^{x,gf}.$$

## Real-Time Data and the Greenbook

- At each FOMC meeting (which occurs 8 times a year), the staff produces a detailed forecast of the economic outlook. The projection horizon varies from six to ten quarters.
- Since March 1996 the staff have stored both the Greenbook projection and the historical data of the series with the forecast.
  - Due to extensive delays in the release of the 1995 NIPA comprehensive revisions databases stored from the first half of 1996 were incomplete. Our analysis begins in September 1996.
- All the forecasts are produced in real-time.
  - The estimation and projection of the models are performed using data as they were known at the time that Greenbook was closed.

## Real-Time Data for the DSGE Model

The DSGE model is estimated on the following series:

- Nominal gross domestic product;
- Nominal cons. expenditure on non-durables & services;
- Nominal consumption expenditure on durables;
- [ Nominal residential investment expenditure; ]
- Nominal business investment expenditure;
- **Three** series of inflation: GDP price inflation, inflation for consumer nondurables and services and inflation for consumer durables;
- Hours (labor input);
- Wage inflation (compensation per hour); and,
- The federal funds rate.

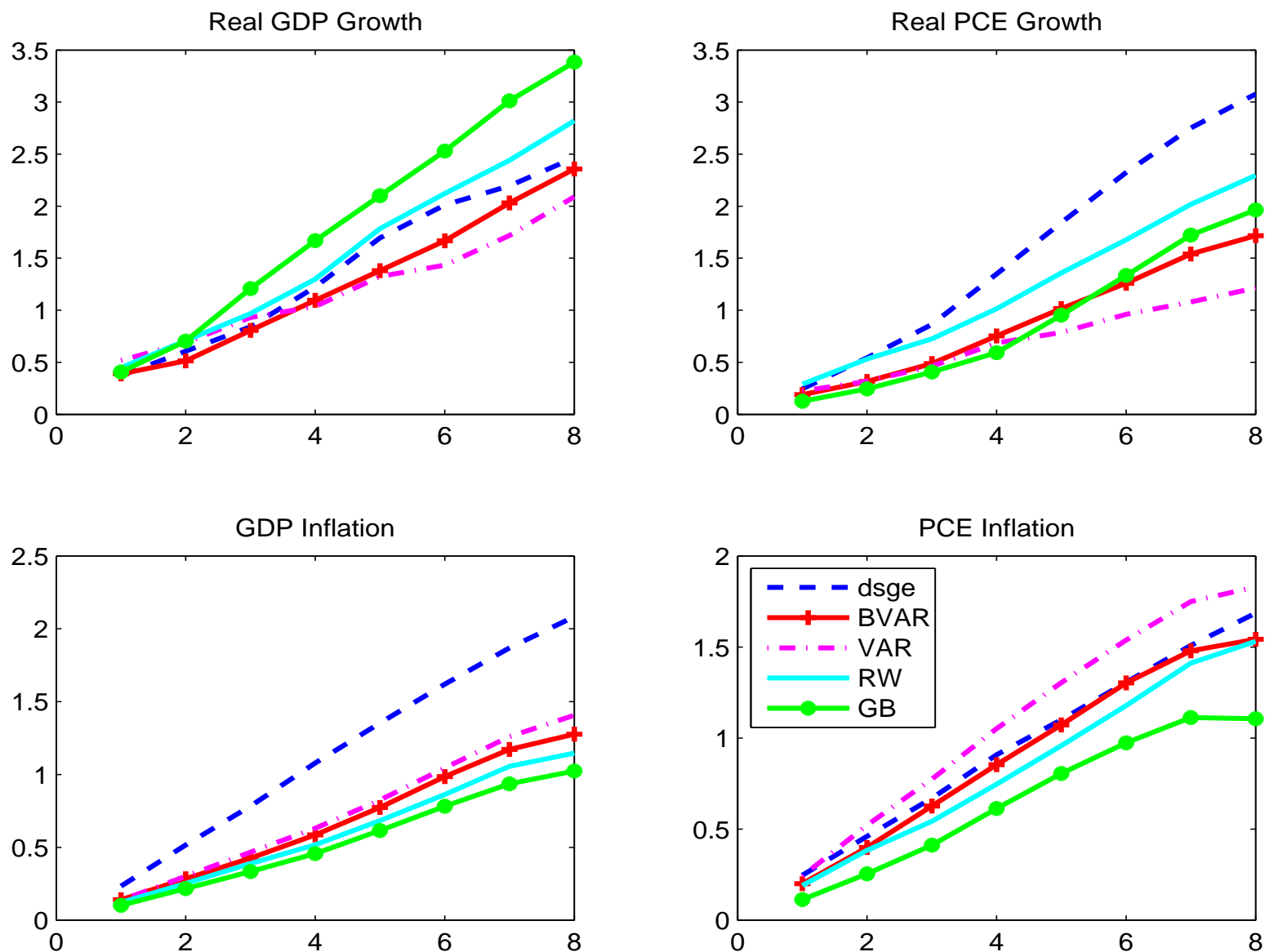
## Real-Time Forecasts

- DSGE model forecast.
- Alternative forecasts.
  - Greenbook;
  - Random walk;
  - VAR (Real GDP growth, Real cons. growth, GDP price inflation, Cons. price inflation and the nominal interest rate.); and,
  - Bayesian VAR (same variables as VAR; modified Litterman prior).
- Model forecasts correspond to the following Greenbook rounds:
  - September 1996 to May 2000 (last date in tightening cycle); and
  - May 2000 to June 2003 (last date in easing cycle).

## Real-Time Estimation

- All the atheoretical models are re-estimated every projection period.
- The DSGE model is re-estimated once year using the data available at the time of the most recent August meeting. By that time, the annual re-benchmarking had become available.
- Some of the DSGE model's coefficients are re-calibrated when the model is re-estimated.
  - These coefficients are set by an automatic procedure that minimizes the distance between the growth rates of key aggregates and their theoretical counterparts.
- The BEA's latest release of a series is considered their most accurate measure and used to assess the forecasts.

Figure 1: Mean Absolute Errors (September 1996 - May 2000)



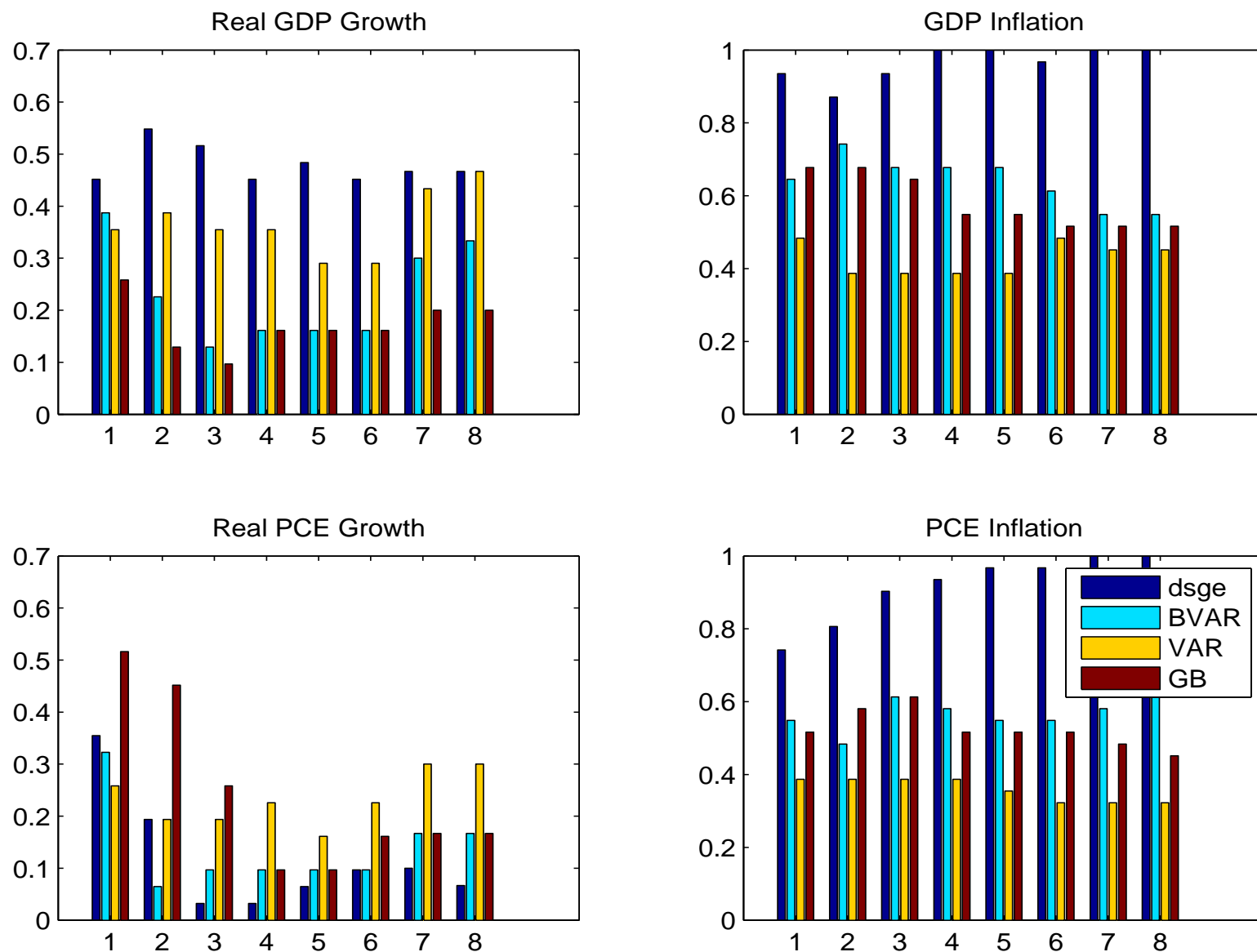
## Mean Absolute Errors: The Late 1990s (I)

- We look at the forecast errors for the September 1996 to May 2000 Greenbook rounds.
- The mean error for Greenbook's real GDP growth forecast one-quarter out is  $\frac{1}{2}$  p.p. This increases  $\frac{1}{2}$  p.p. for each quarter that the forecast extends.
- The Greenbook's poor performance for GDP growth is well documented (see Tulip, 2005, and Tetlow and Ironside 2005).
  - A random-walk forecast outperforms the Greenbook forecast.
- The DSGE model forecasts real GDP growth relatively well.
  - It outperforms both the Greenbook and random-walk forecasts.

## Mean Absolute Errors: The Late 1990s (II)

- The DSGE model does not forecast real PCE growth well.
  - It performs worse than the random-walk and Greenbook forecasts.
- Clearly, in the DSGE model forecast there are large offsetting errors for the expenditure components of real GDP growth.
- The DSGE model's forecast for GDP price inflation performs poorly.
  - Its forecast errors are at least double that of the Greenbook and random-walk forecasts.
- The DSGE model's forecast for PCE price inflation has notably larger errors than the Greenbook and random-walk forecasts.
- The Greenbook outperforms any other model in predicting inflation.

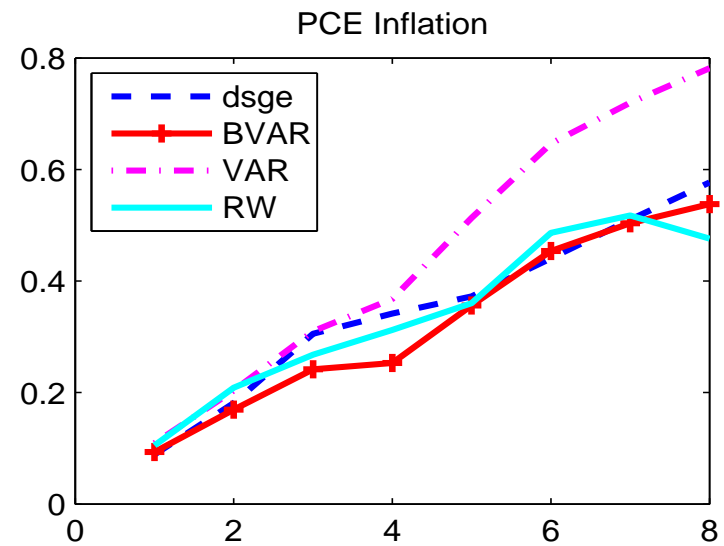
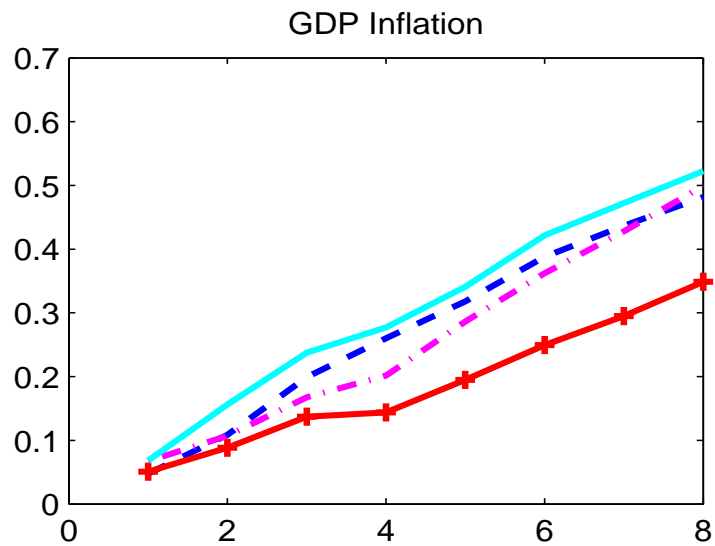
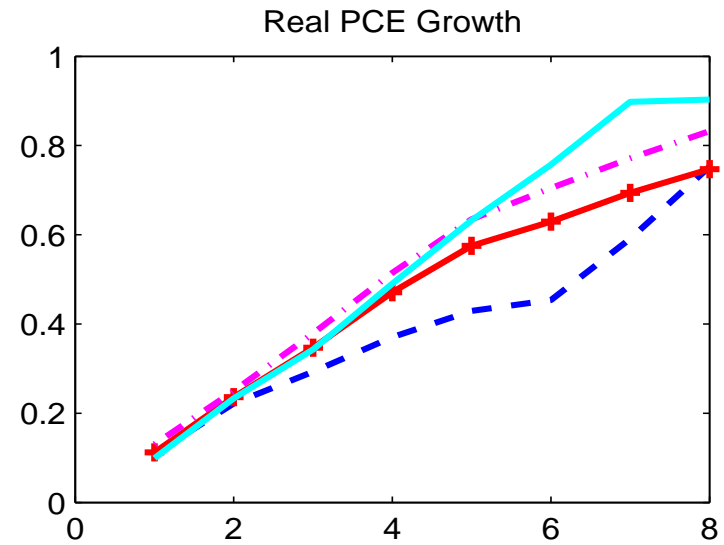
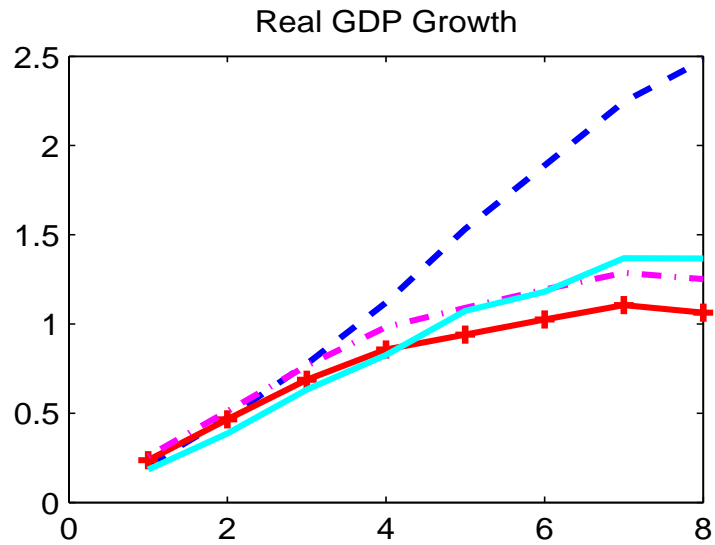
Figure 2: Fraction of Forecast Errors Greater than Zero (Sept 1996 - May 2000).



## Fraction of Positive Forecast Errors: The Late 1990s

- The Greenbook forecast generally under-predicts real GDP growth in the late 1990s.
  - The DSGE model under- and over-predicts at the same rate.
- Both the DSGE model and Greenbook consistently under-predict real PCE growth, although the DSGE model does so more often.
  - The DSGE model must be consistently over-predicting investment growth and/or exogenous spending growth.
- The Greenbook forecast under- and over-predicts inflation at about the same rate.
  - The DSGE model almost always over-predicts inflation, because it expects inflation to eventually return to its sample mean.

Figure 3: Mean Absolute Errors (May 2000 - Jun 2003)

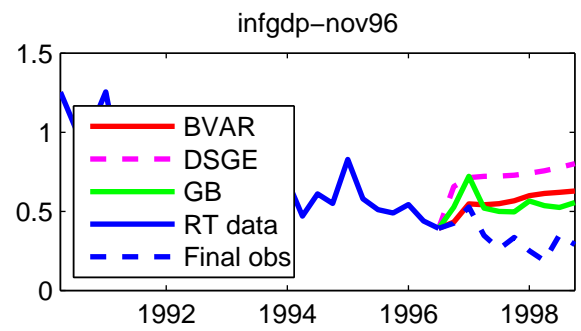
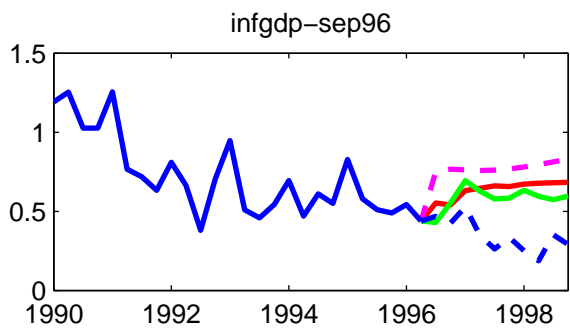
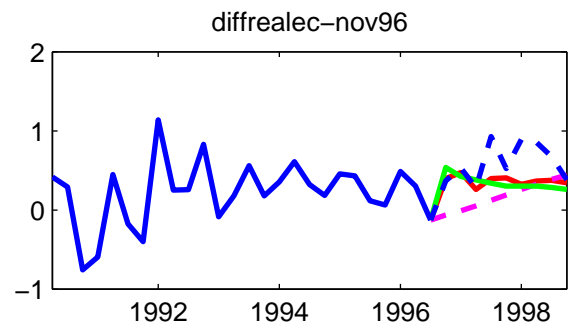
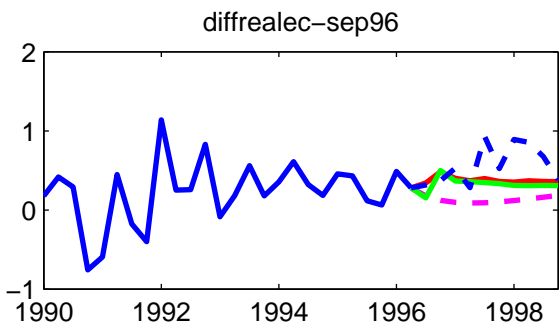
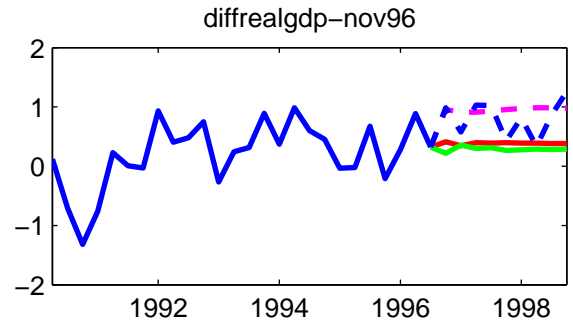
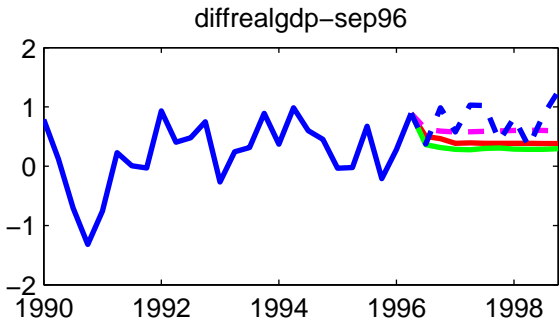


## Mean Absolute Errors: Recession and Early Recovery

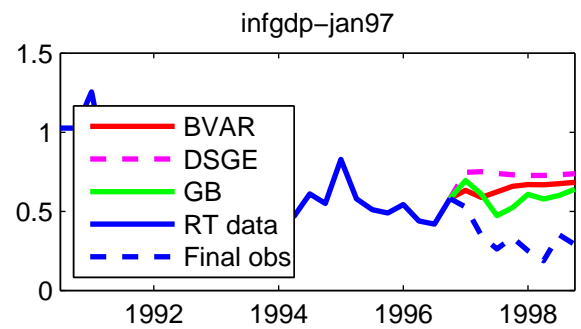
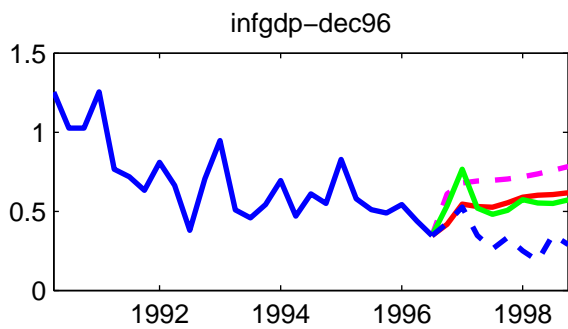
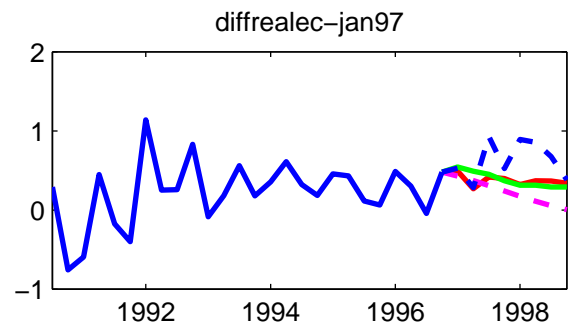
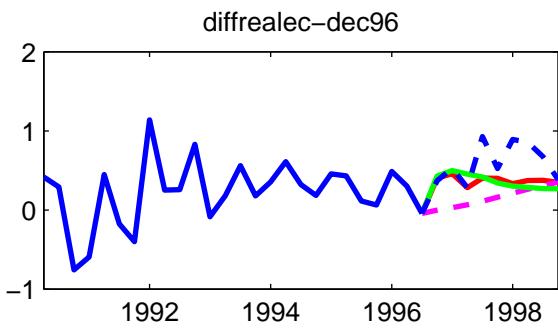
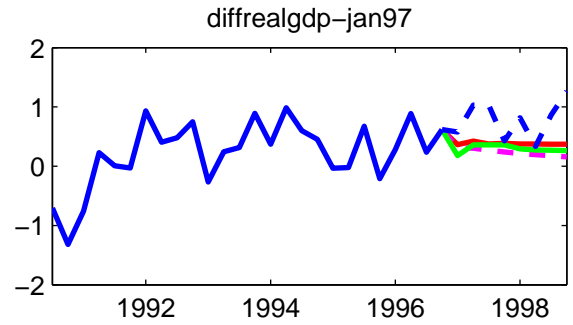
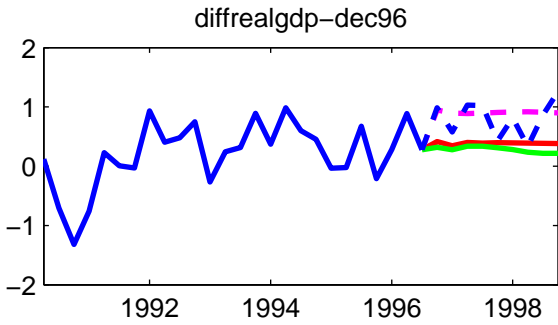
- Whereas the DSGE model has relatively small forecast errors for real GDP growth in the late 1990s, it has relatively large errors in the early 2000s.
  - In an absolute sense, however, its forecast errors are about the same across the two periods.
- In addition, while the DSGE model had relatively large forecast errors for real PCE growth in the late 1990s, it has relatively small errors in the early 2000s.
  - In an absolute sense, however, all of the forecast errors for consumption are smaller in the latter period.
- The forecast errors for inflation are smaller in the latter period.

## Conclusions

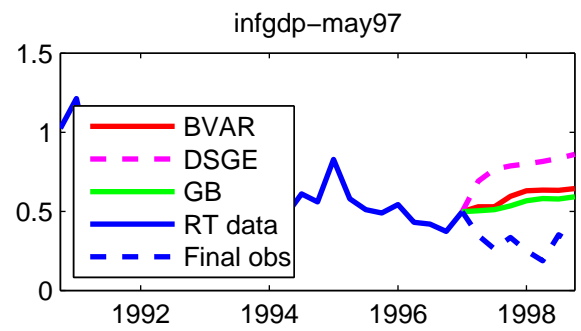
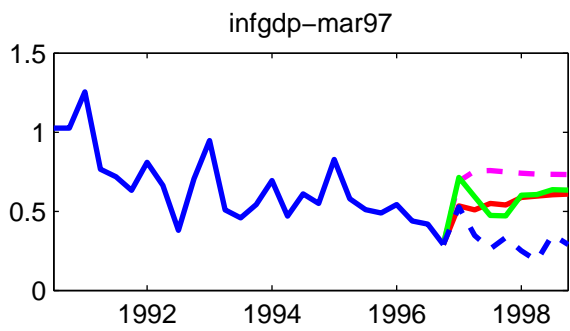
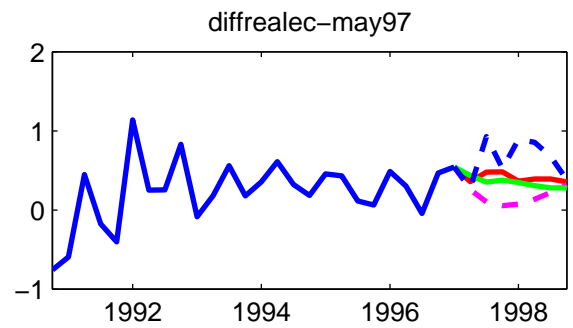
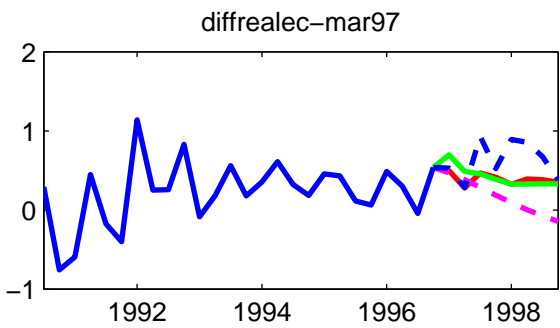
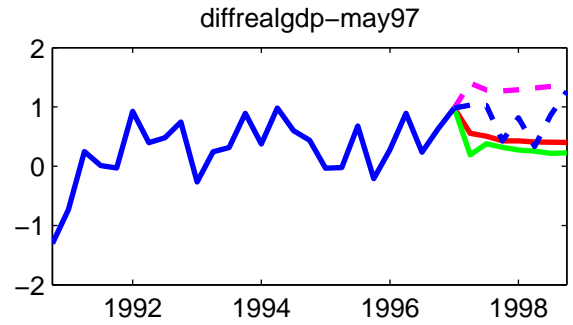
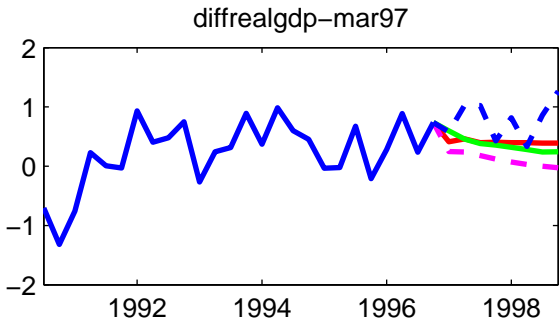
- The current version of our DSGE model provides forecasts that compete in terms of accuracy with popular alternative models.
- Arguments for including estimated DSGE models in the suite of models available to the central banks: Strong storytelling content and good forecasting performance.
- Nonetheless, our results indicate that for forecasting purposes the model can be improved along a number of dimensions, including:
  - Improved modelling of agents expenditures decisions (such as introducing rule-of-thumb spenders and a financial accelerator).
  - Improved determination of the economy's steady-state.
- Future work must also consider conditional forecasting.



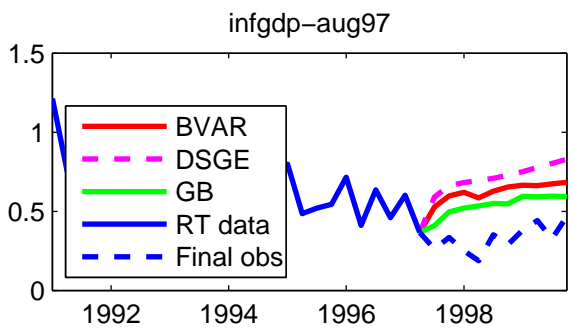
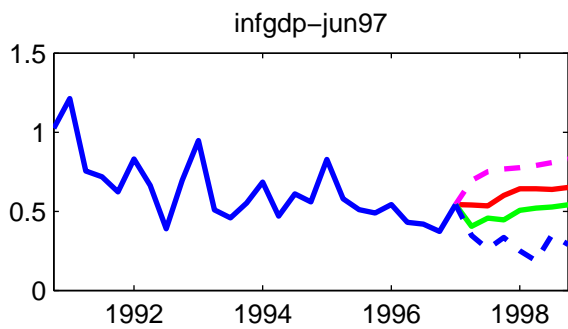
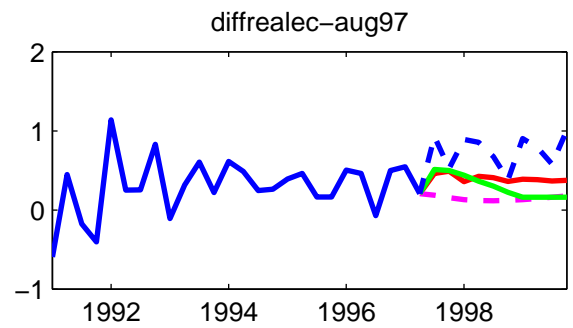
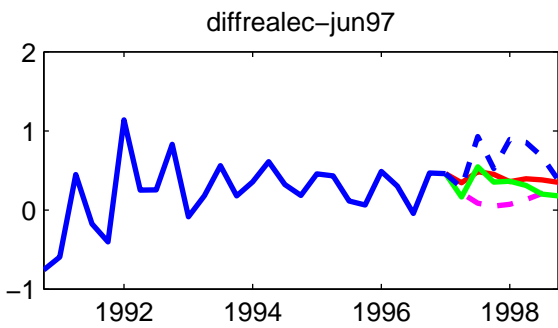
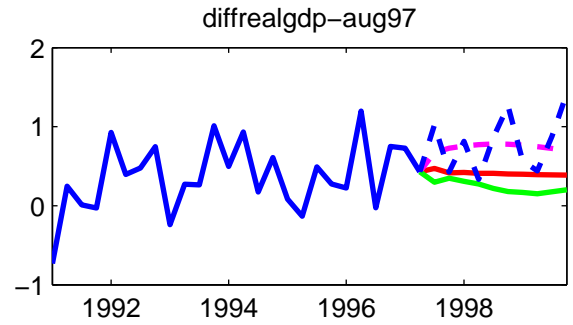
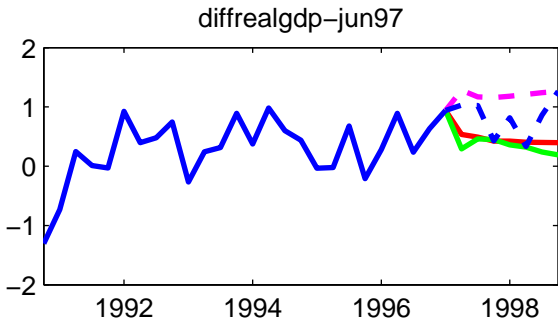
- BVAR
- - - DSGE
- GB
- RT data
- - - Final obs

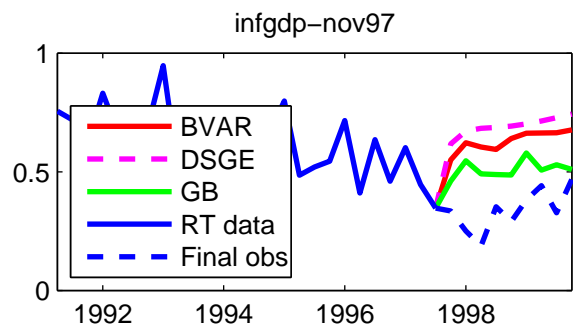
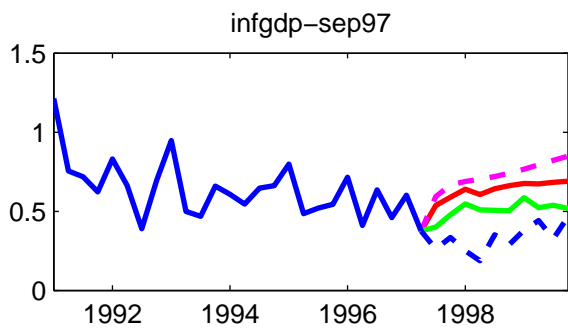
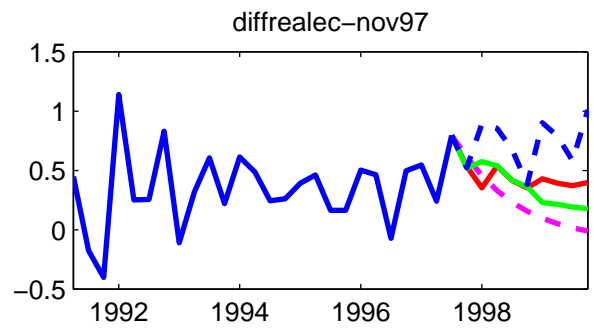
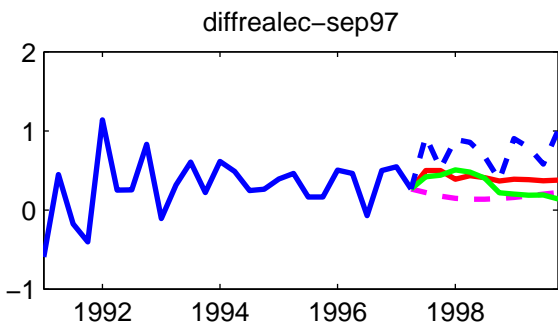
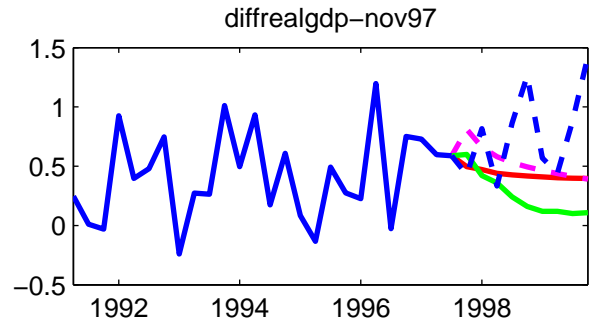
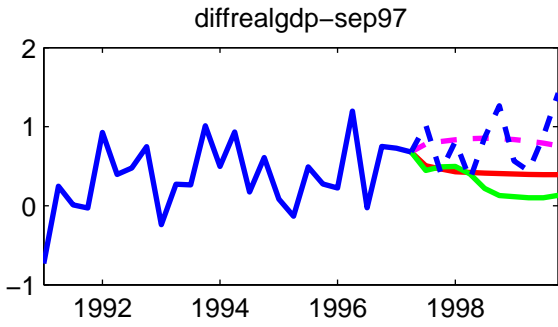


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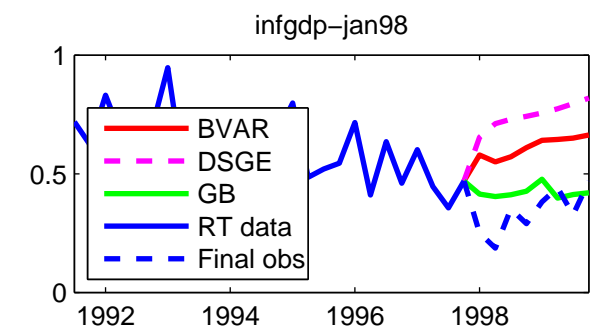
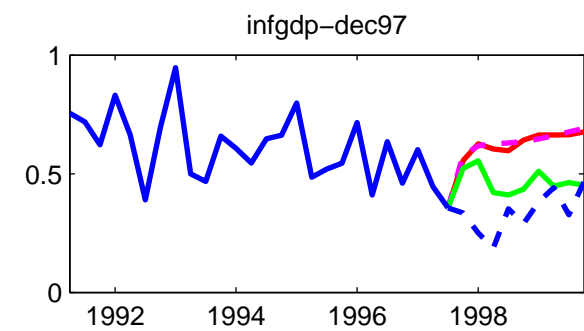
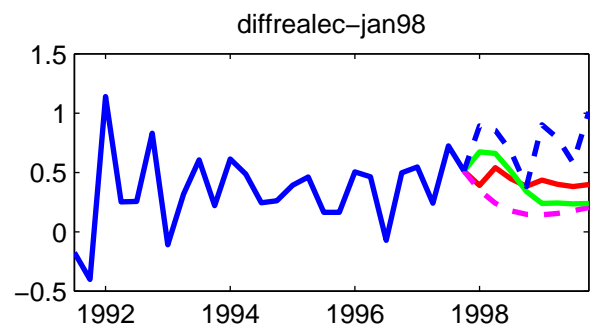
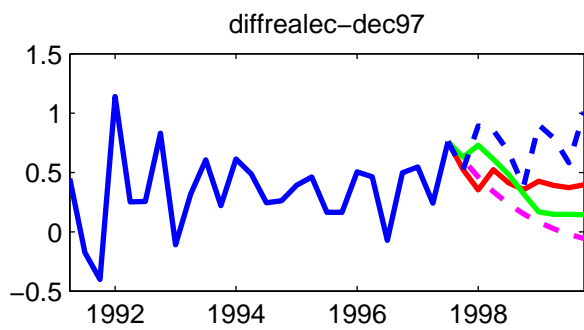
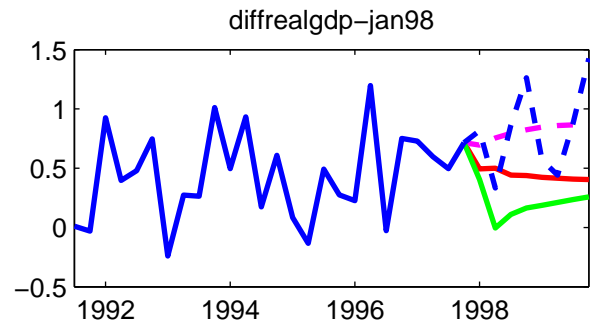
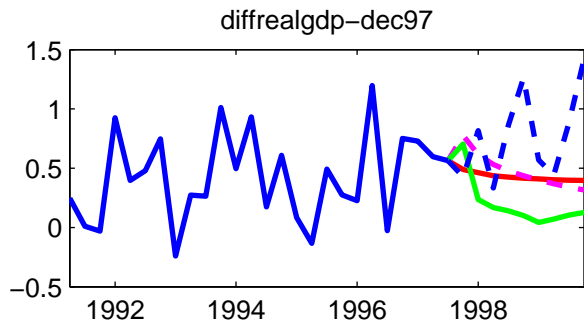


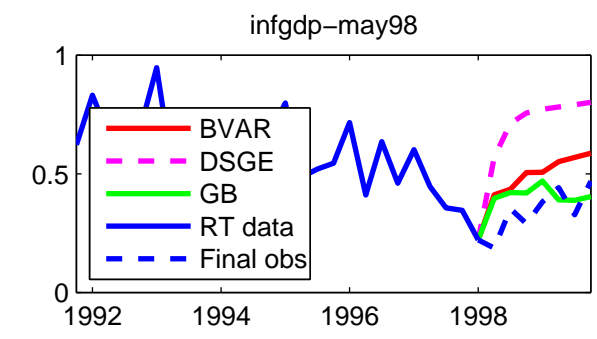
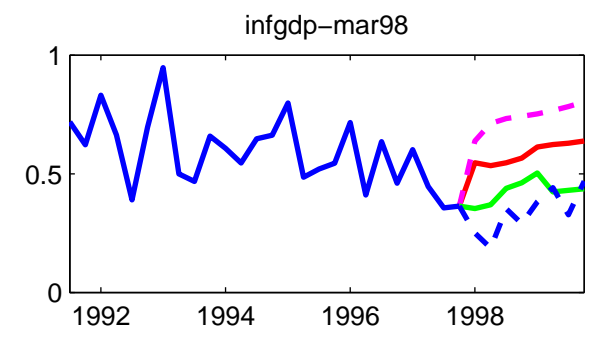
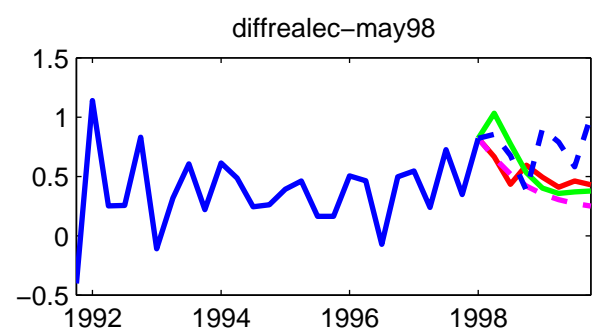
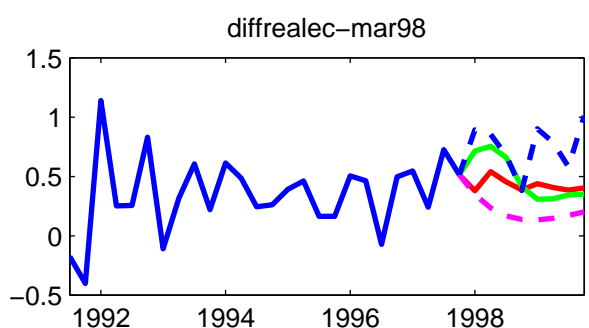
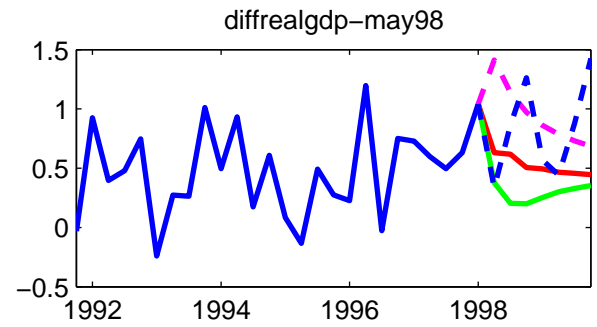
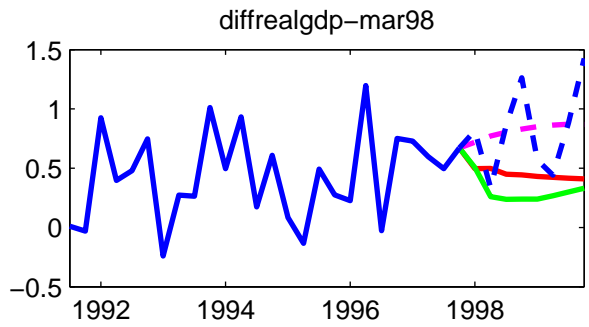
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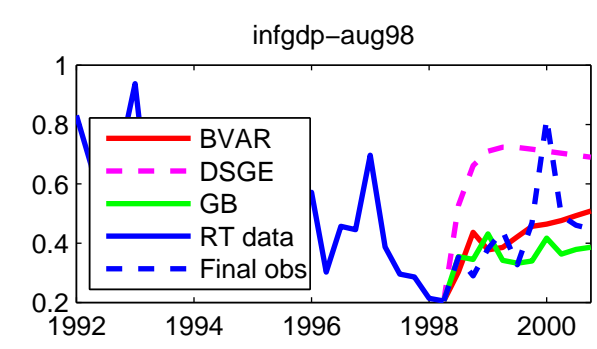
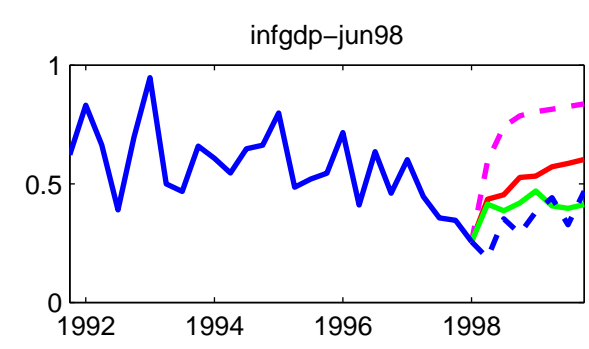
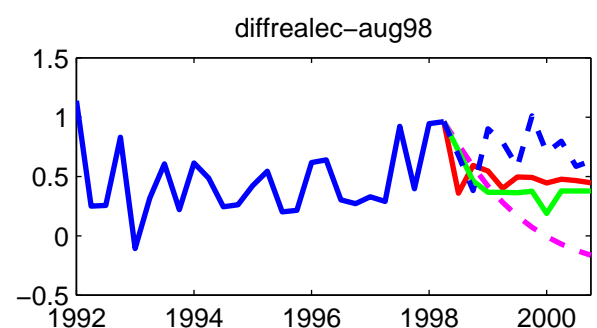
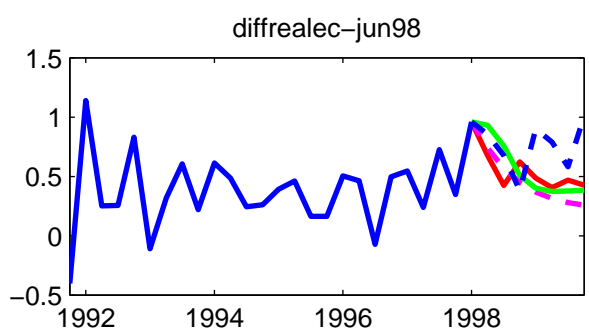
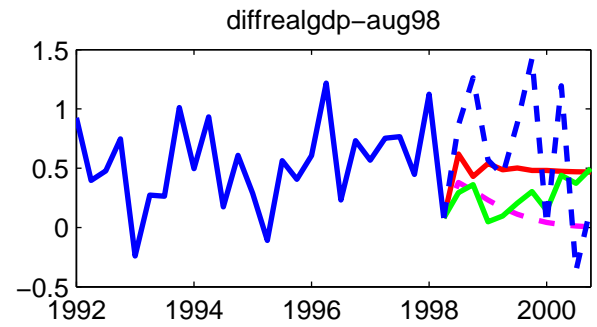
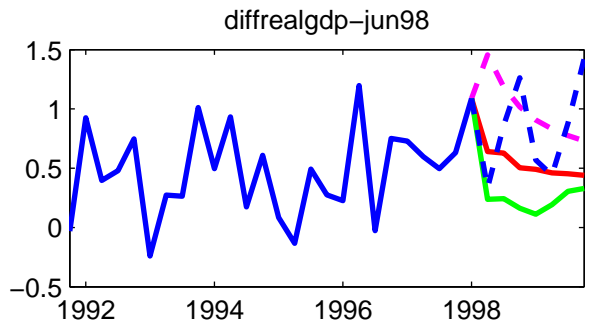


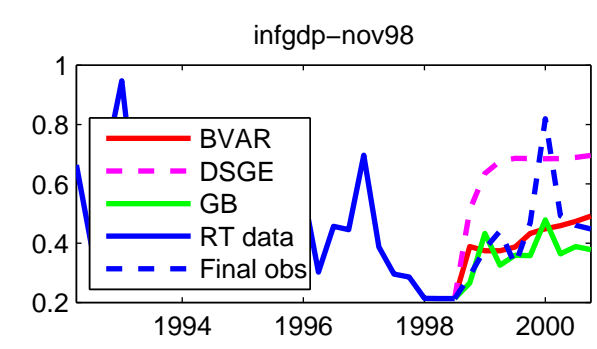
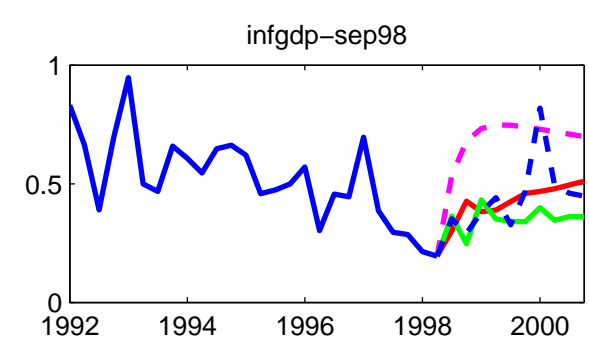
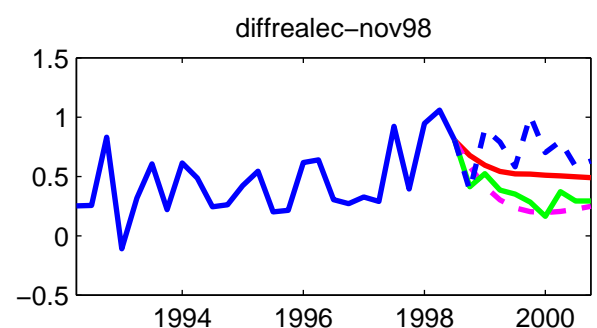
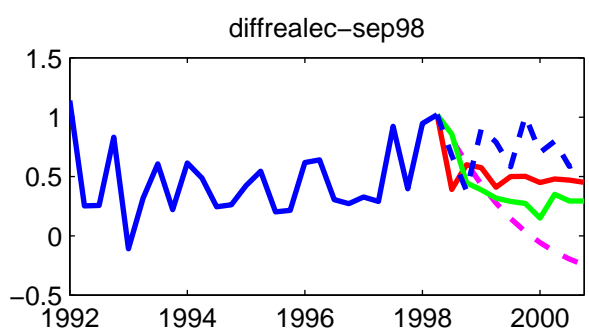
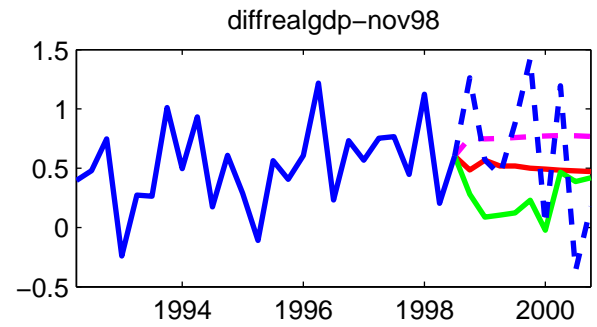
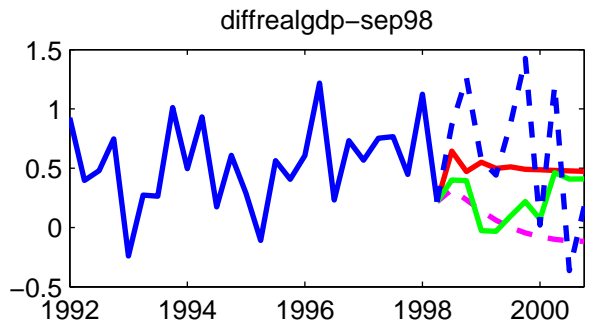


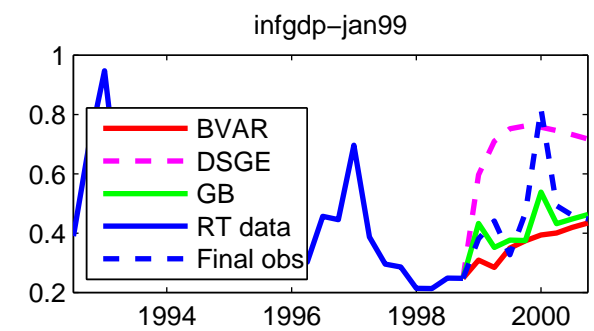
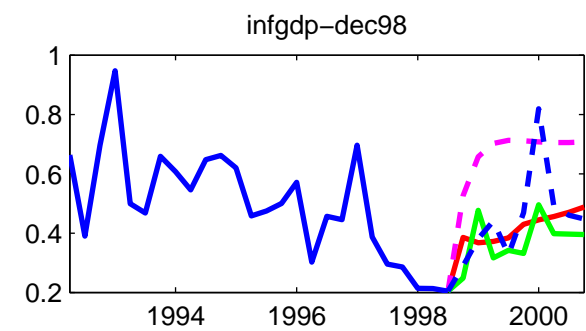
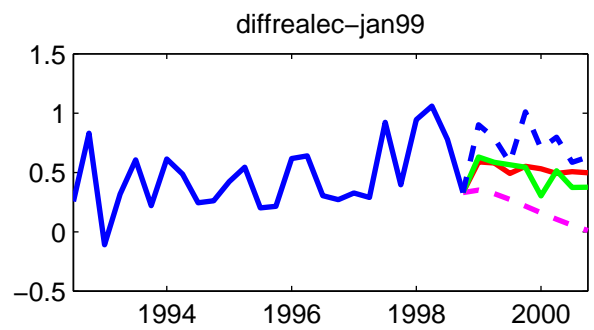
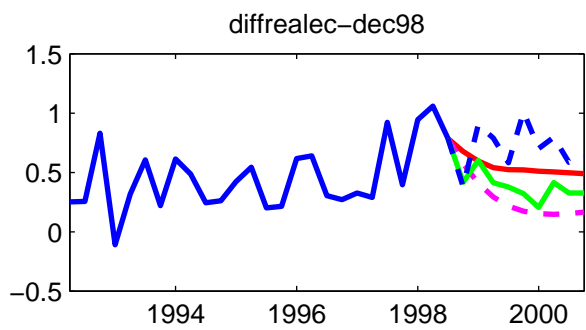
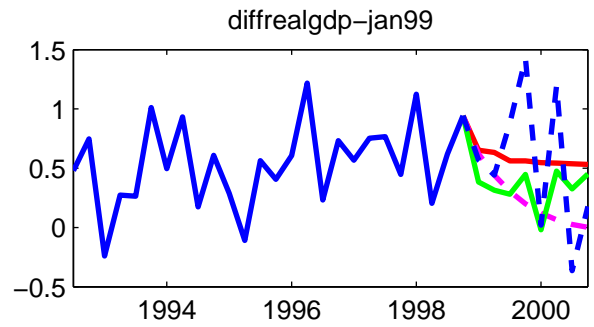
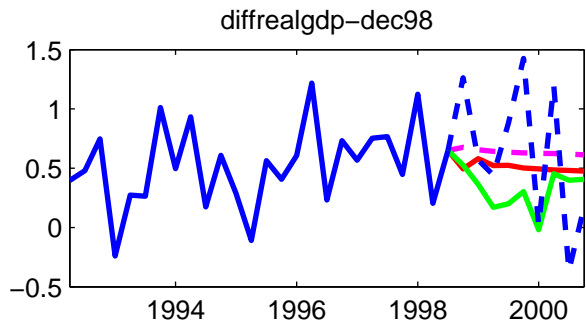
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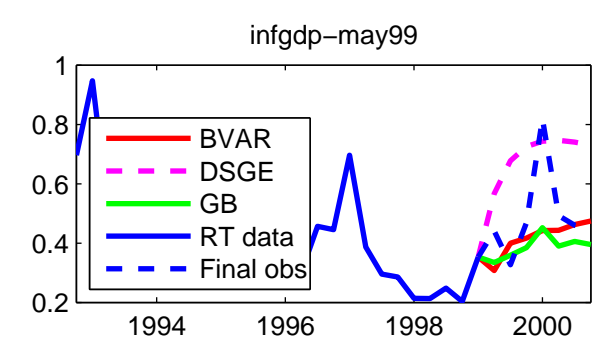
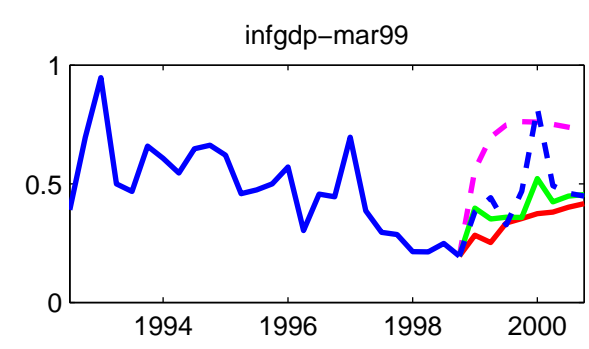
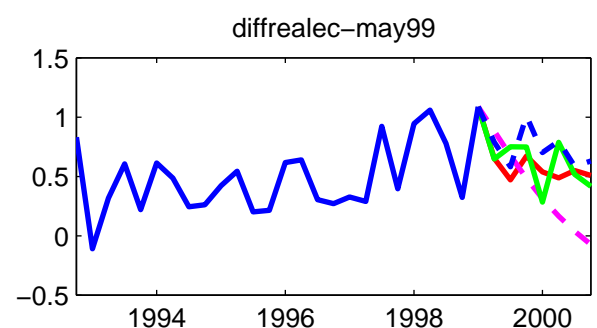
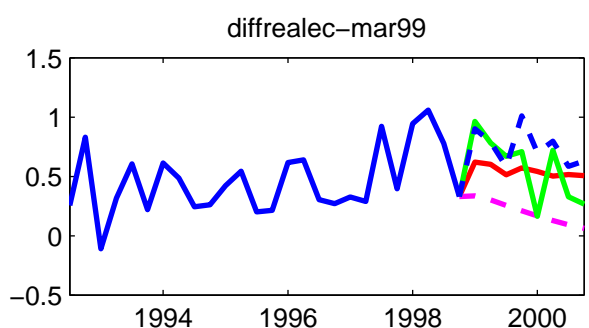
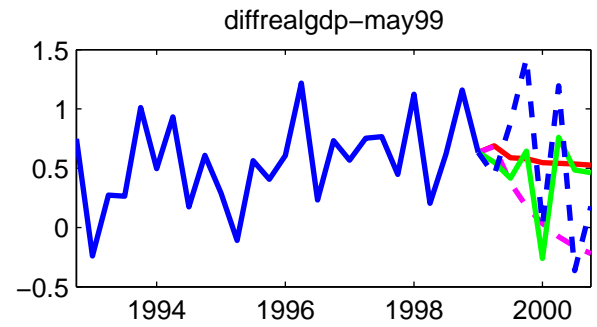
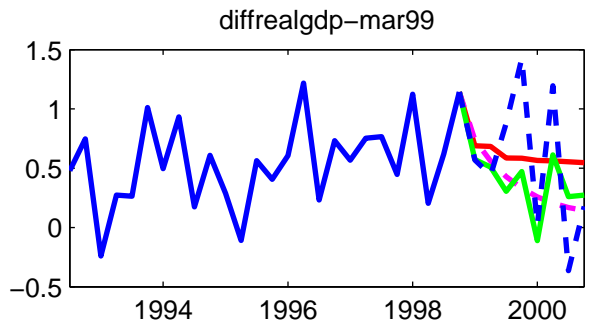


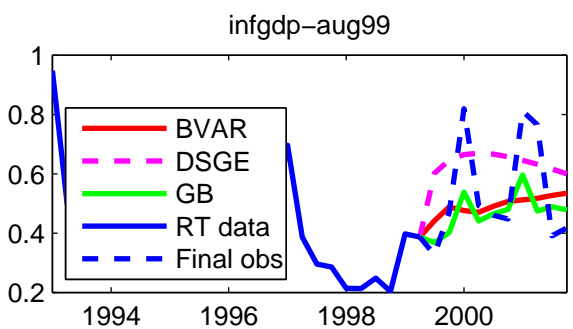
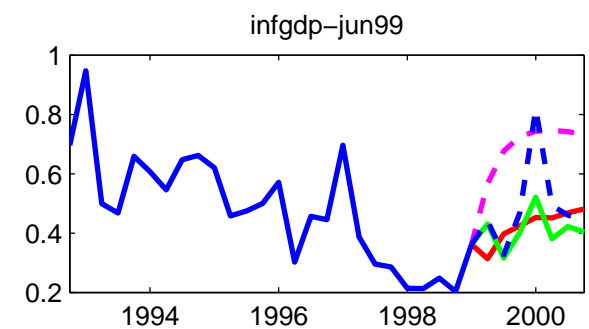
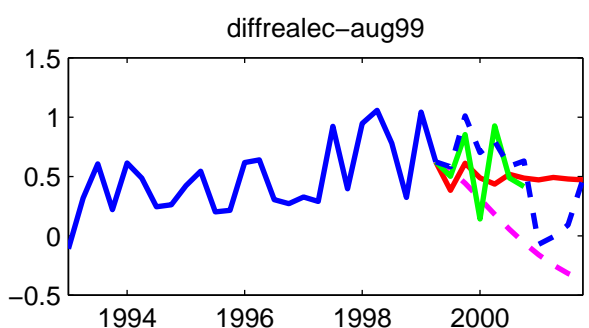
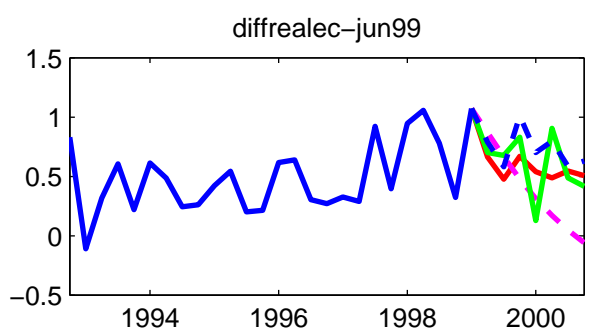
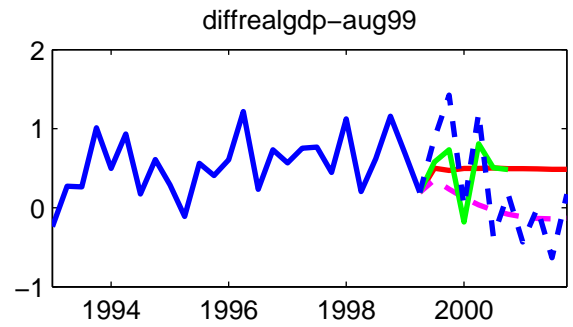
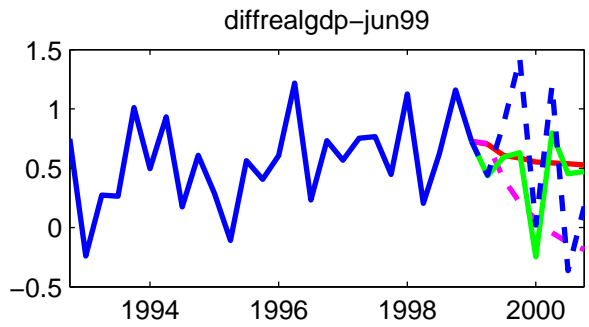


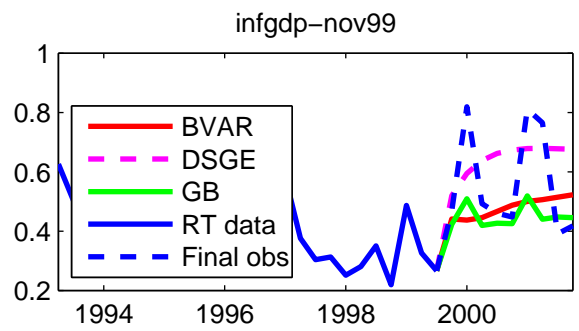
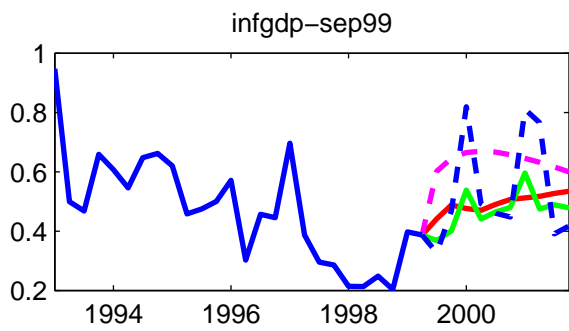
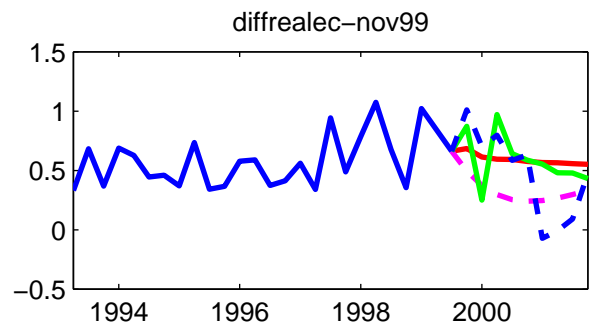
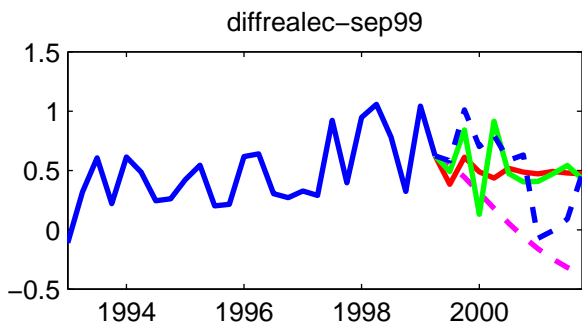
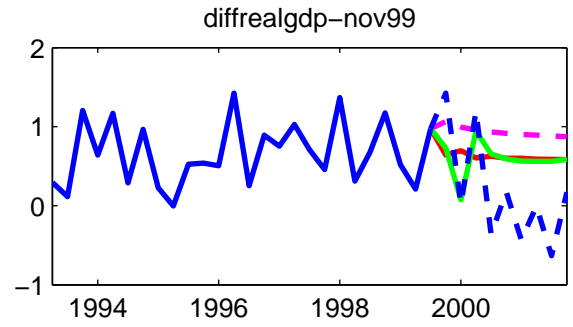
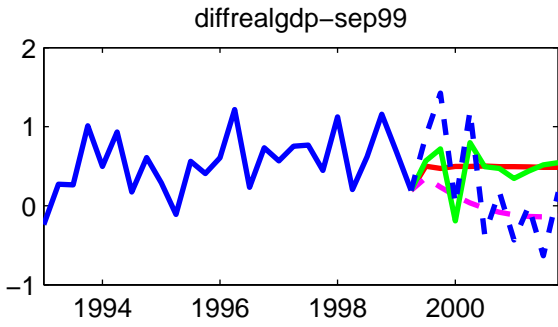


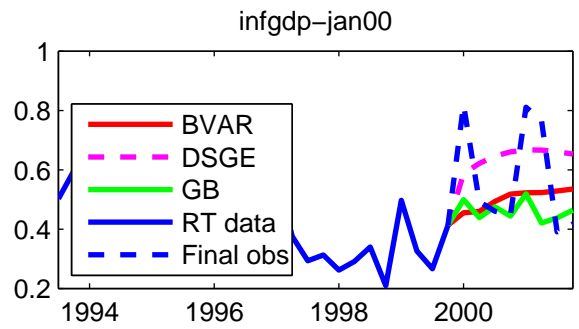
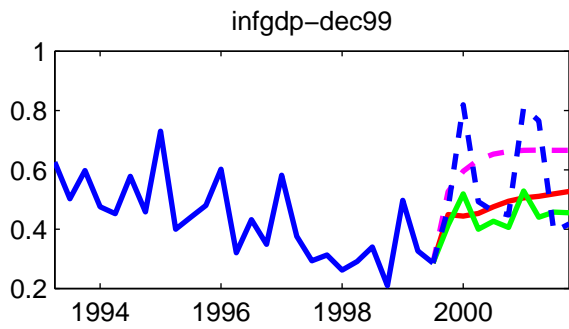
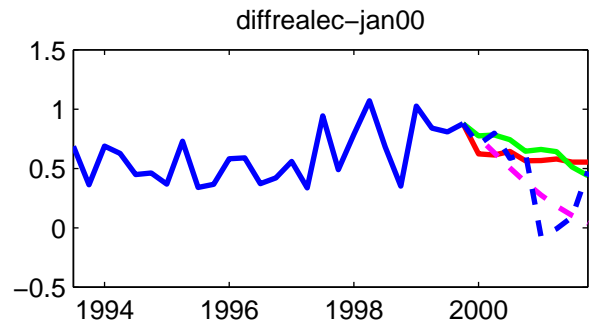
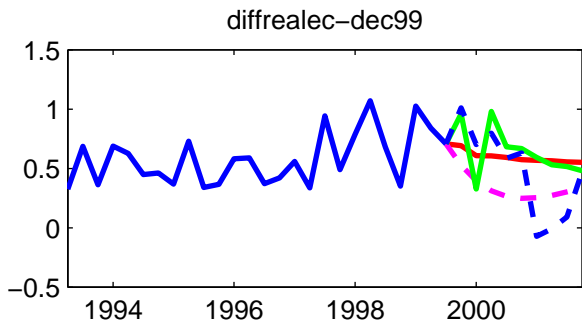
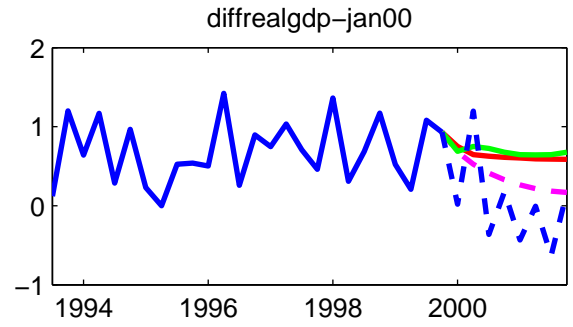
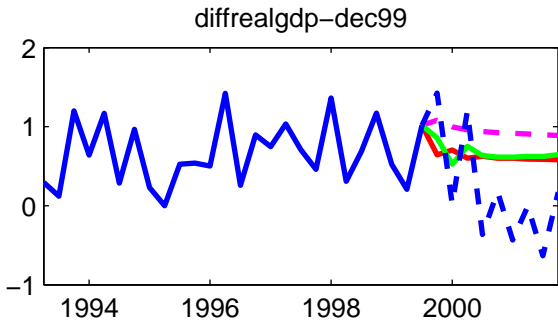


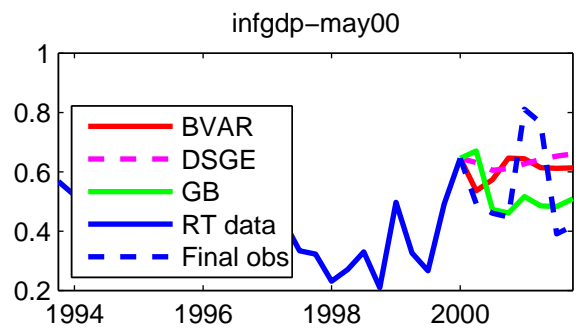
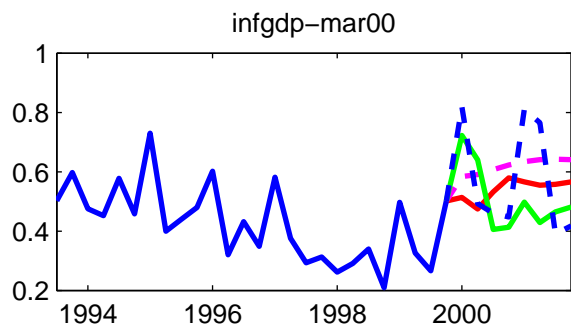
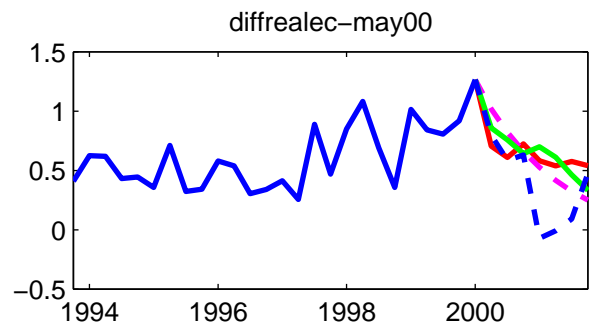
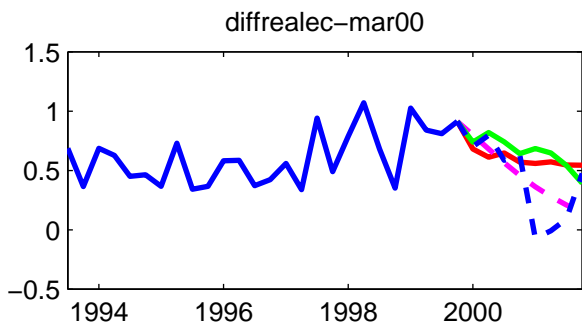
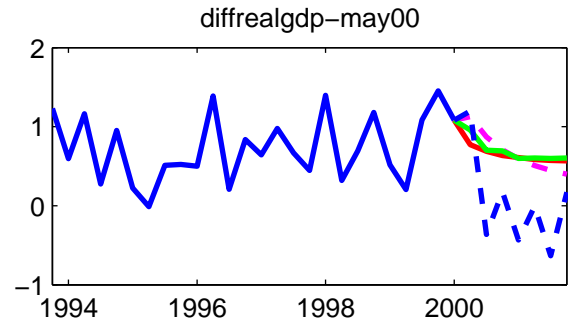
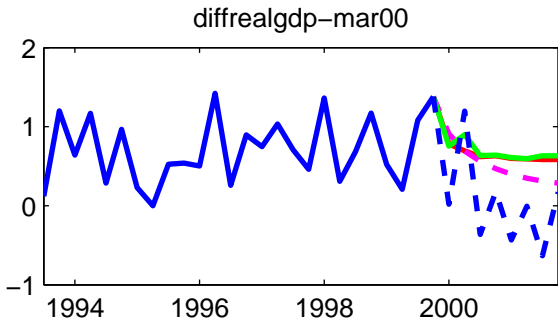
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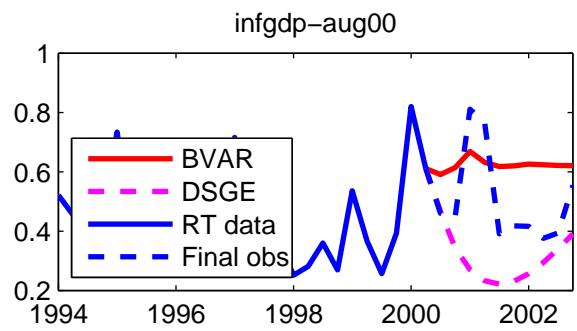
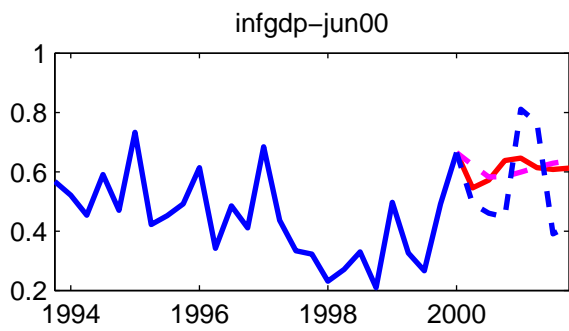
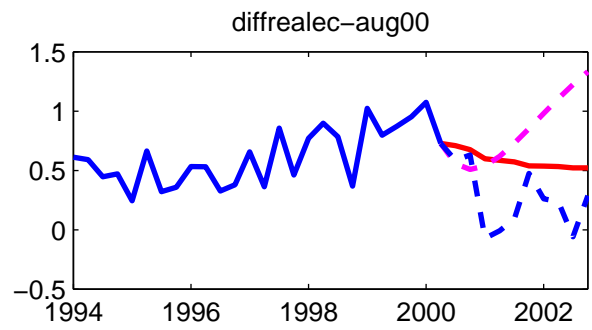
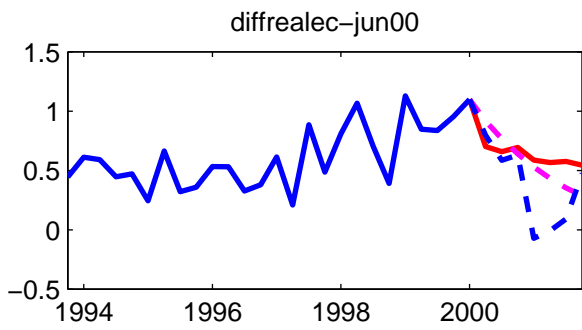
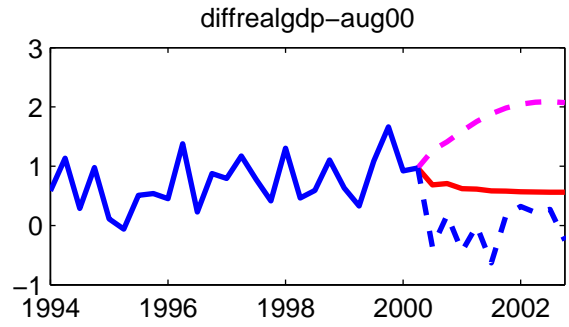
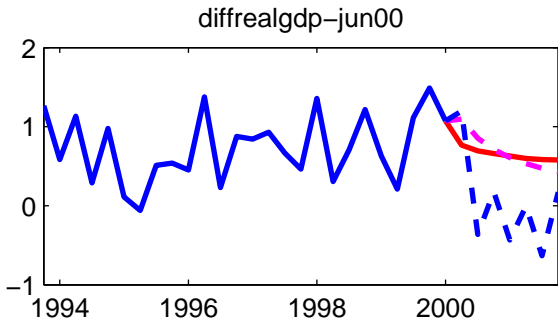


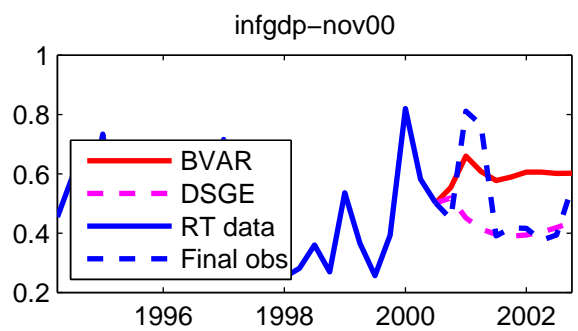
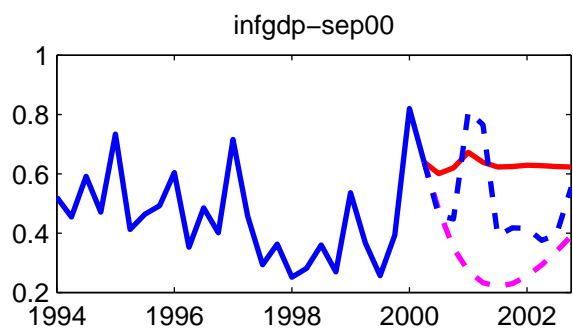
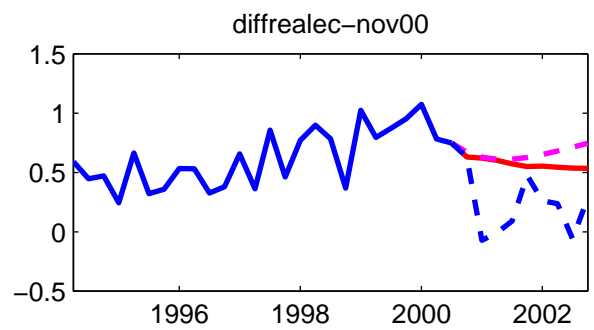
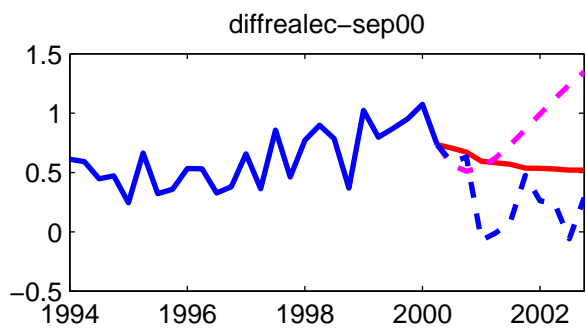
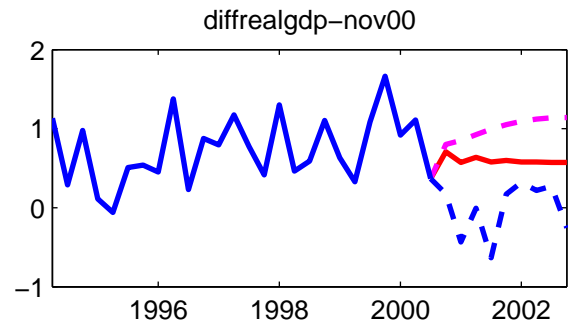
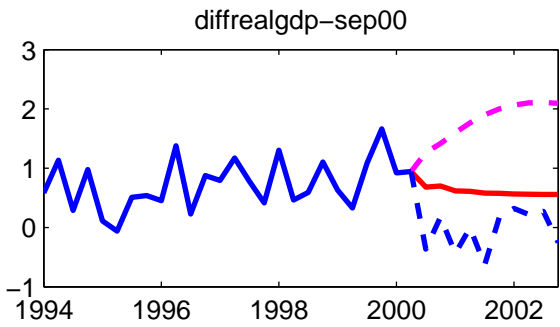


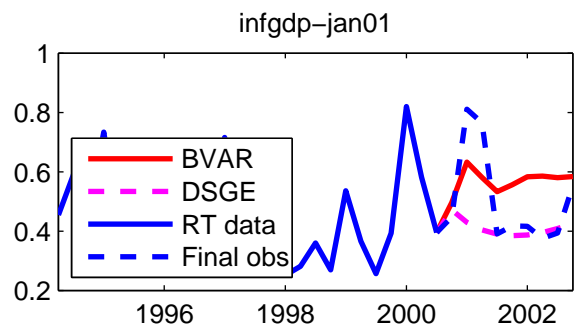
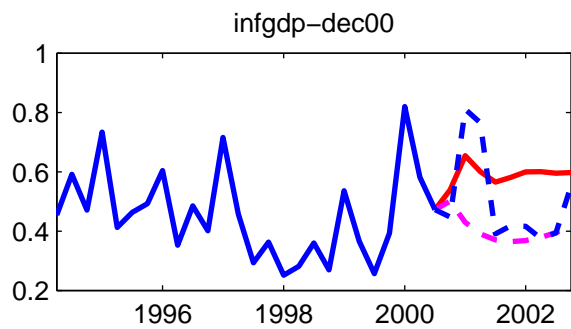
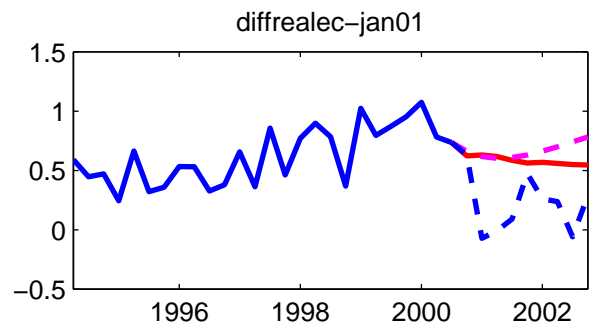
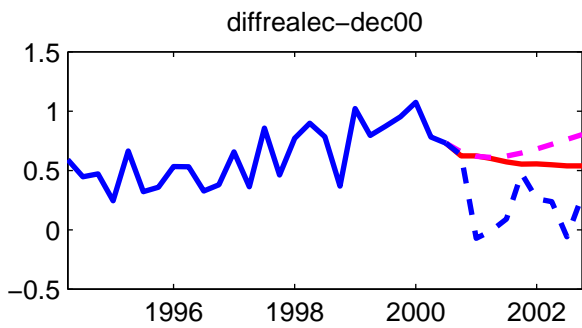
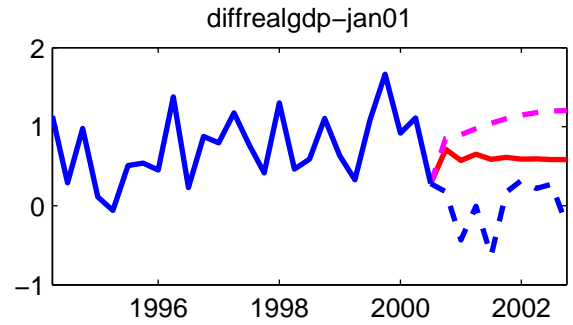
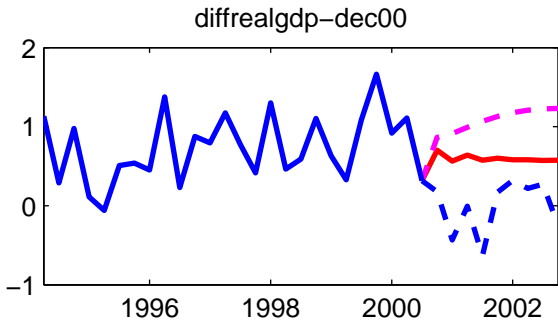


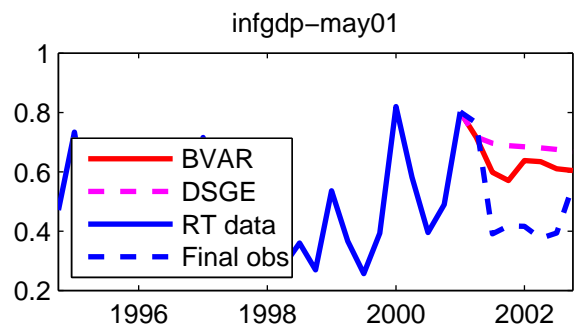
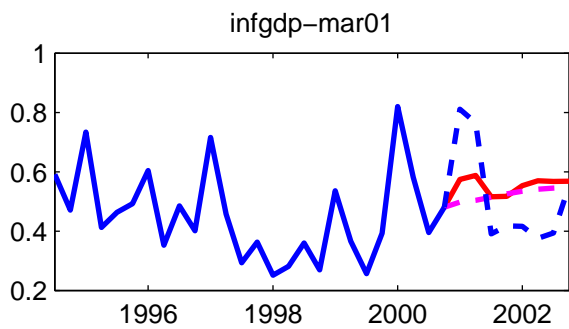
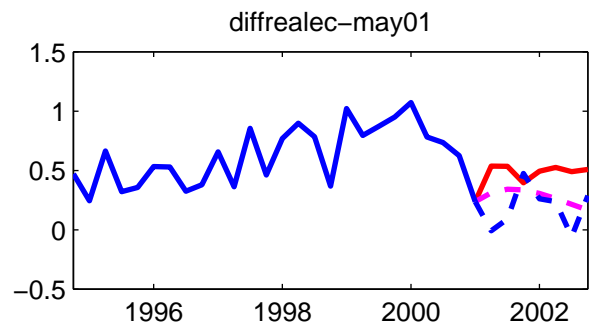
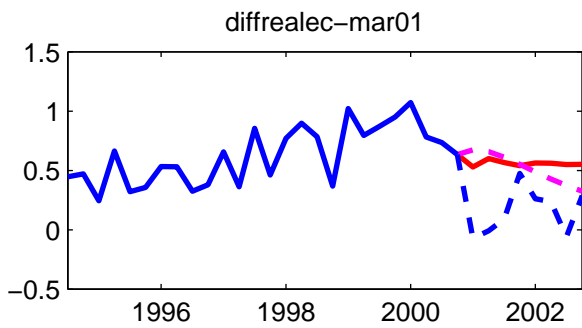
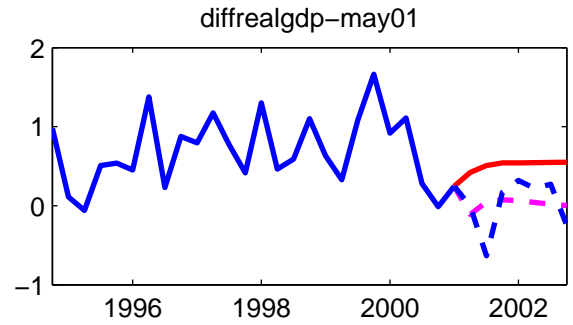
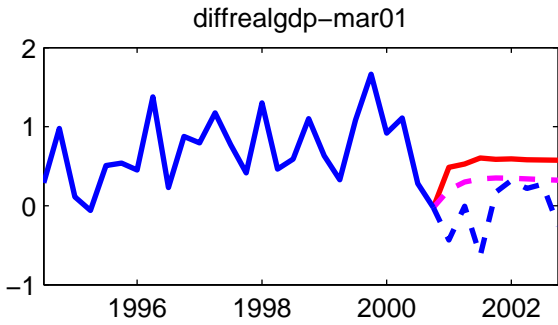


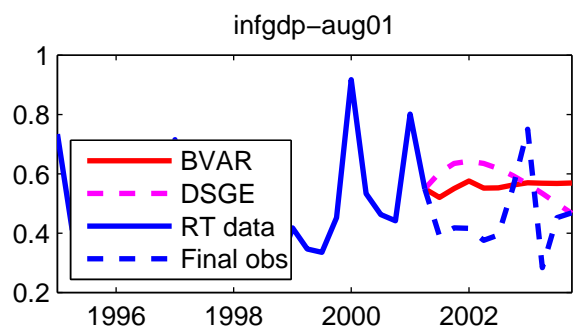
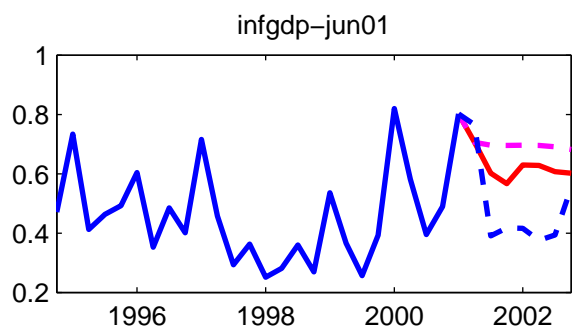
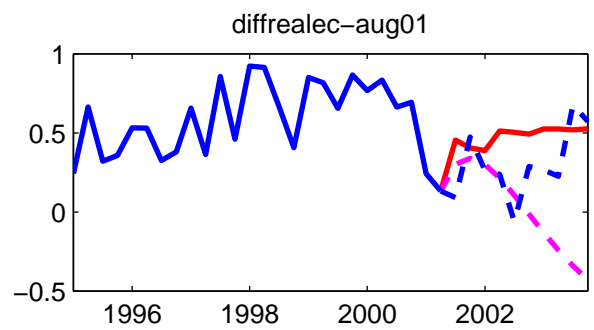
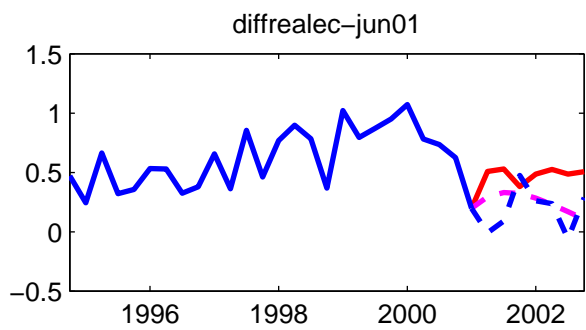
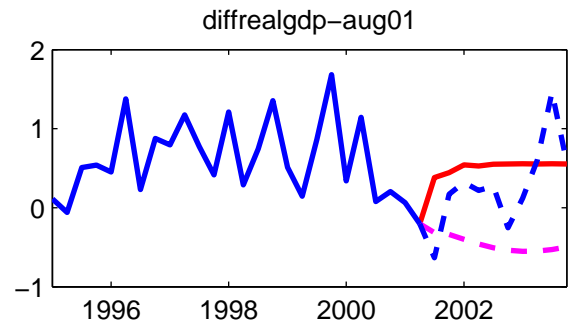
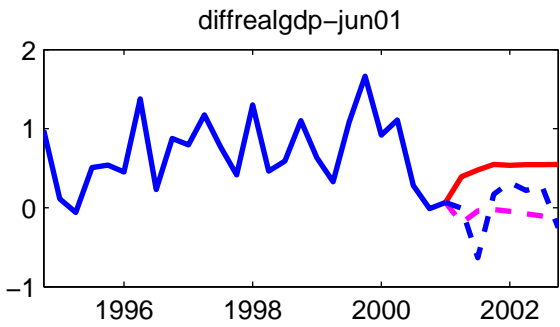


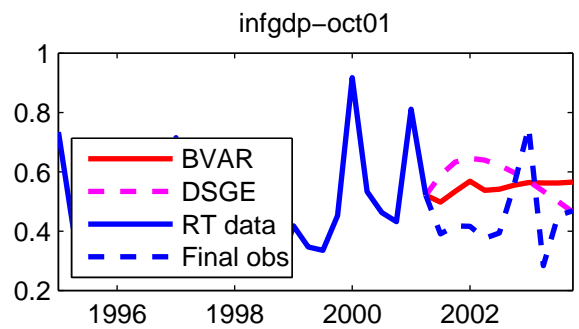
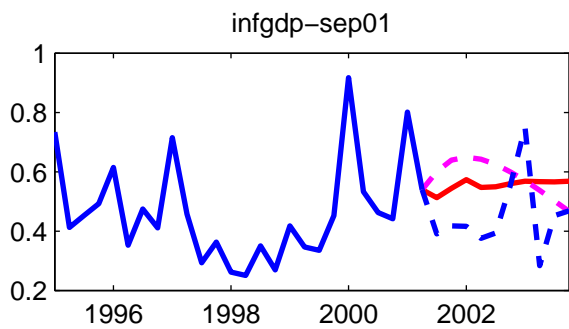
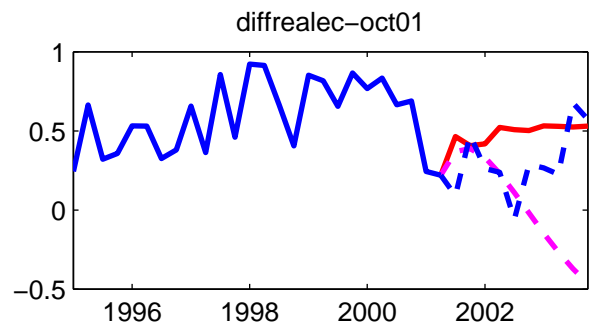
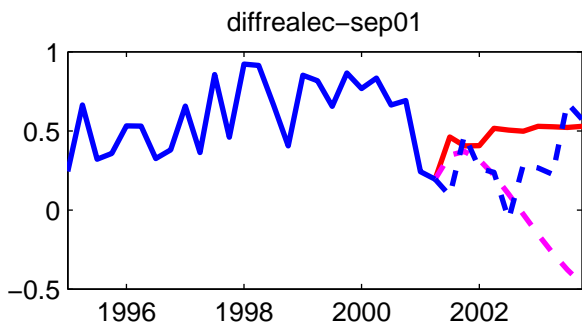
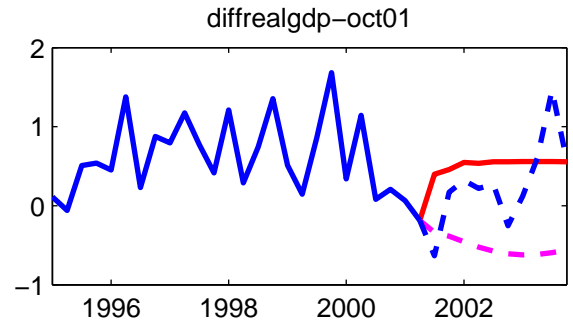
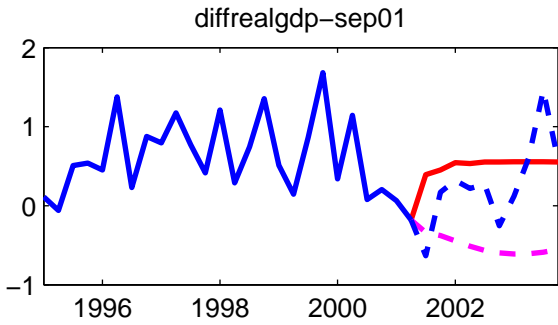


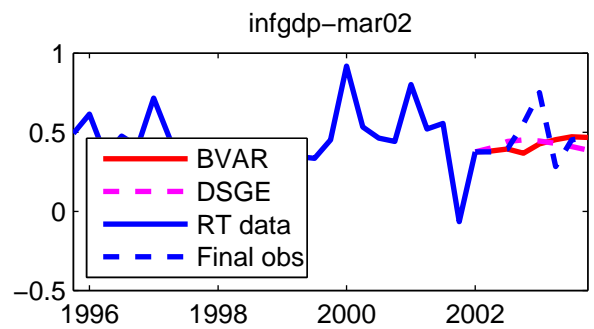
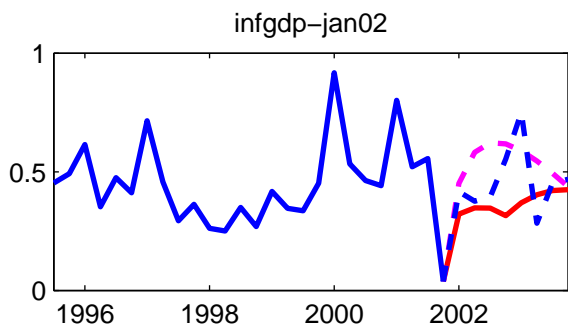
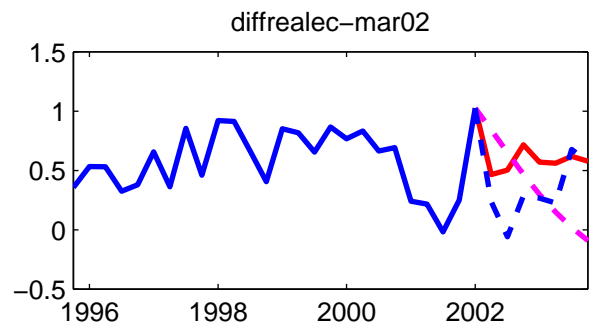
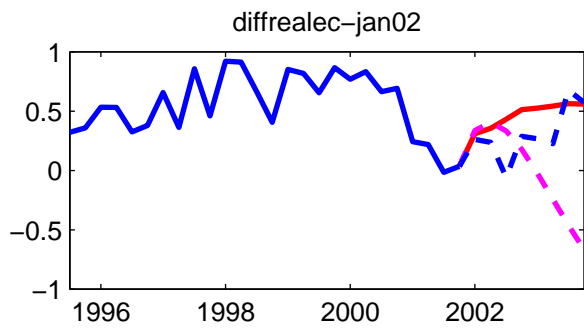
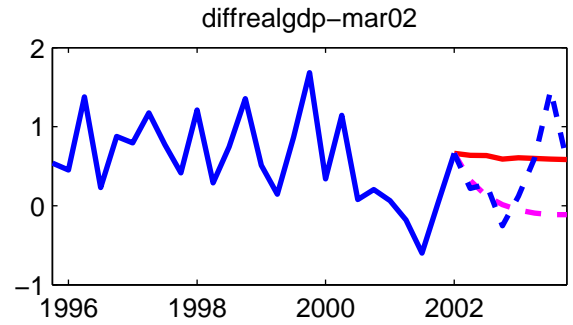
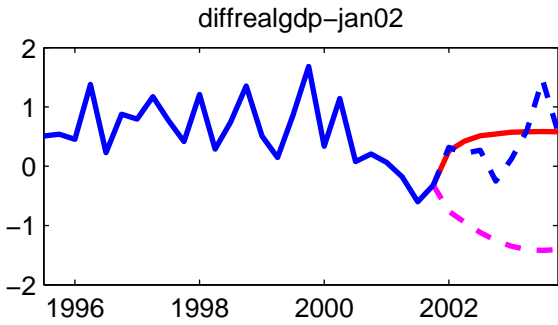




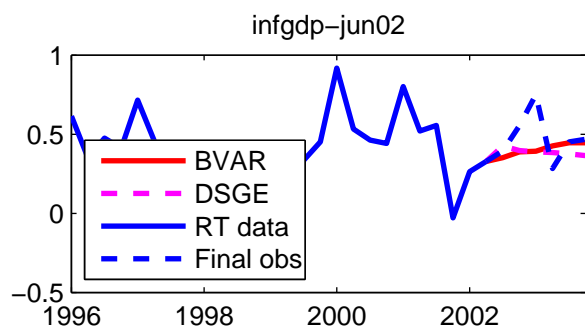
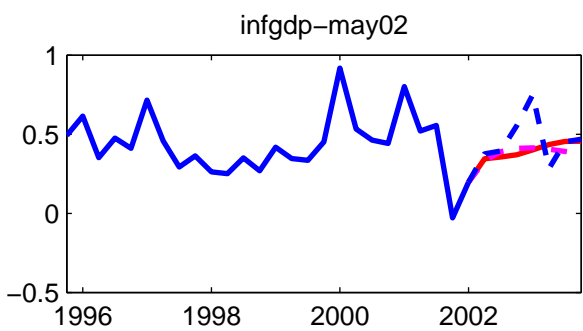
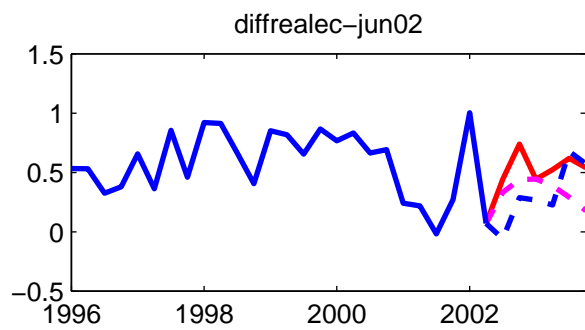
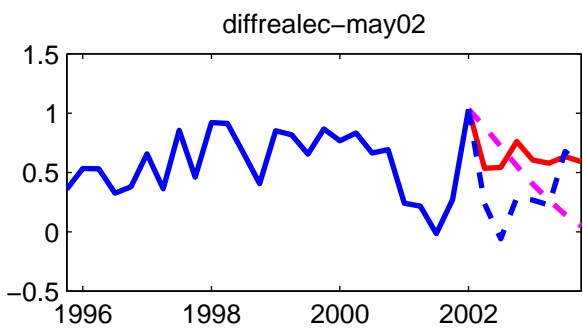
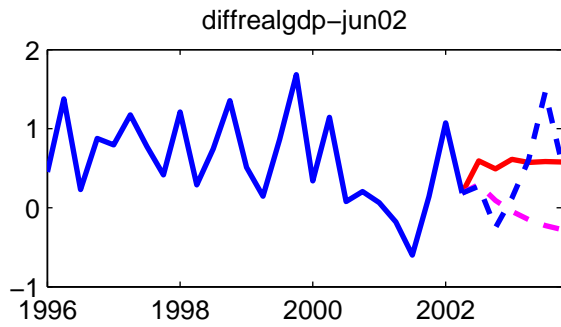
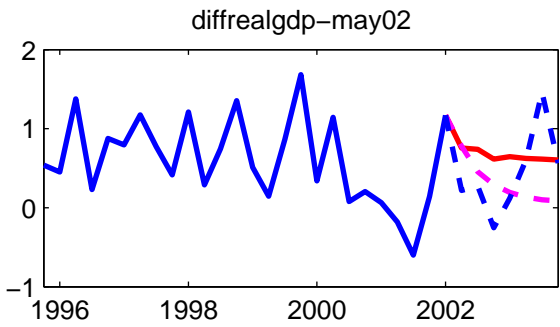


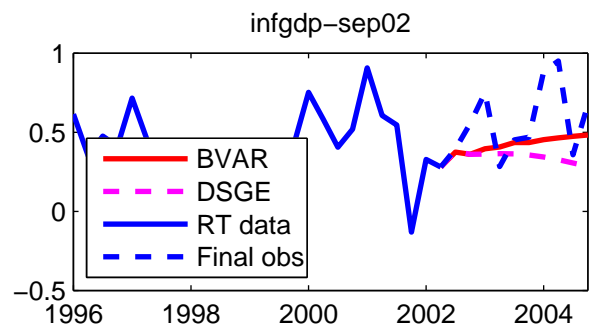
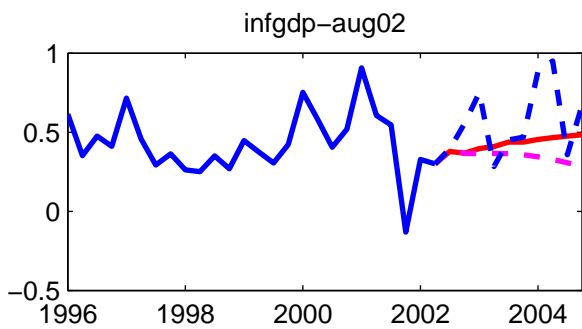
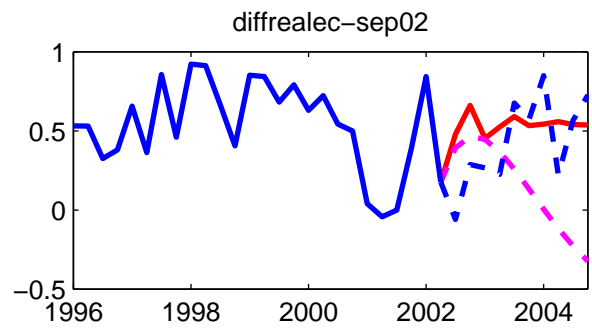
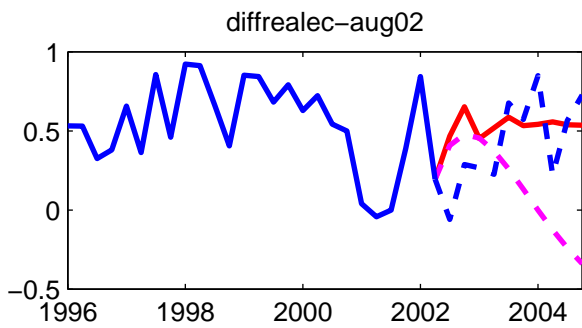
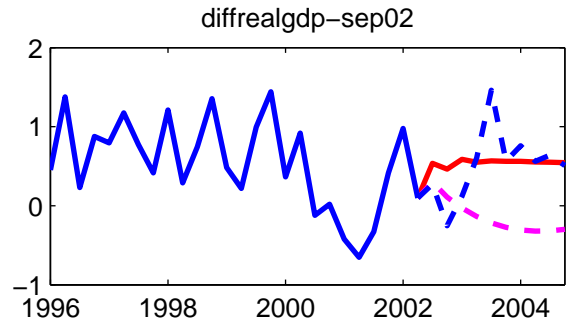
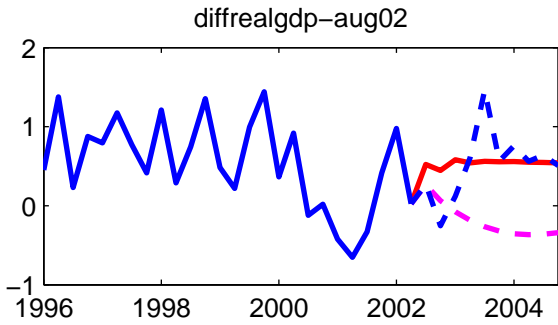


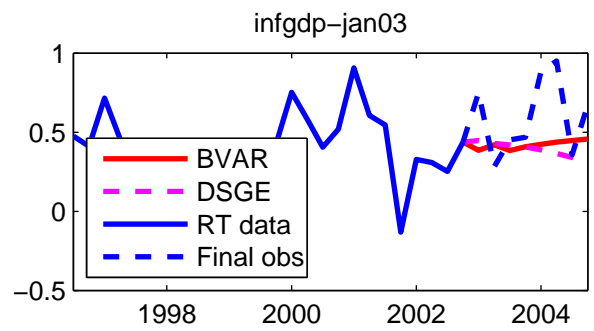
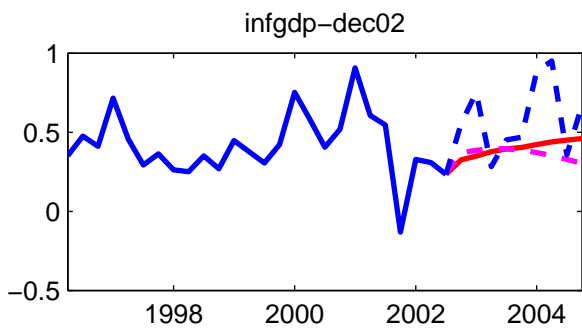
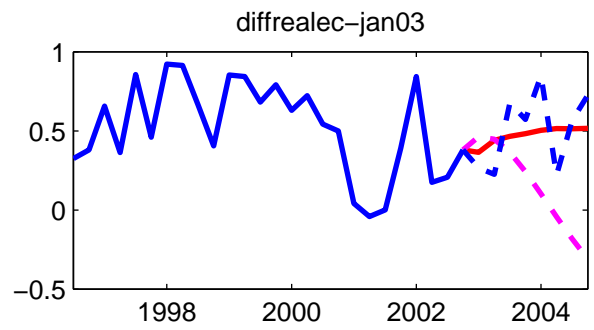
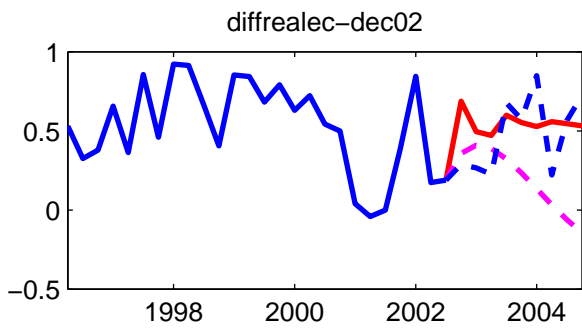
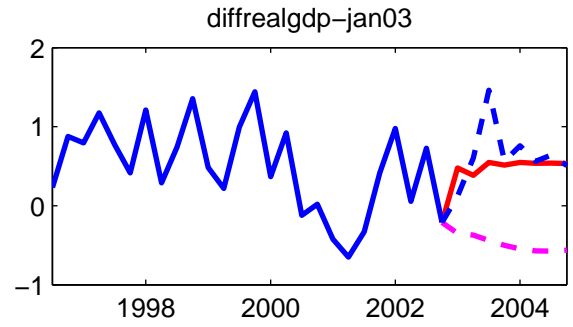
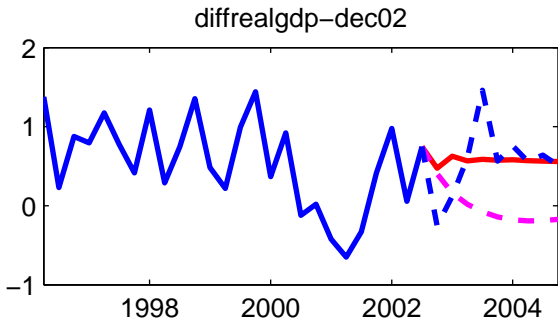




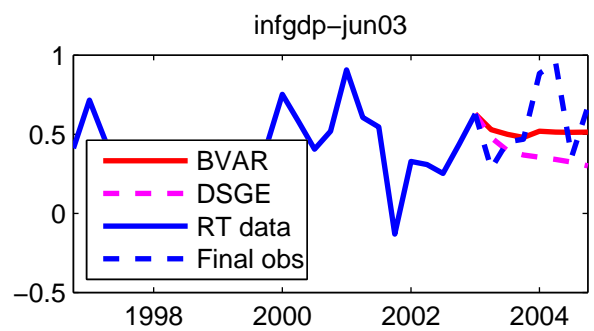
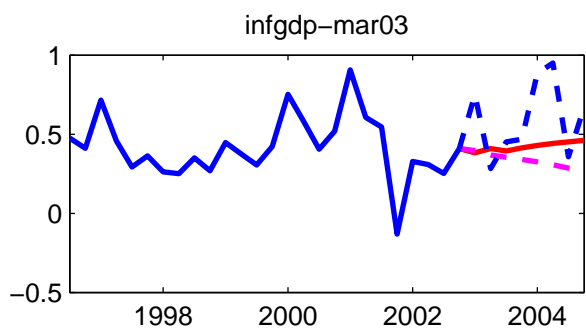
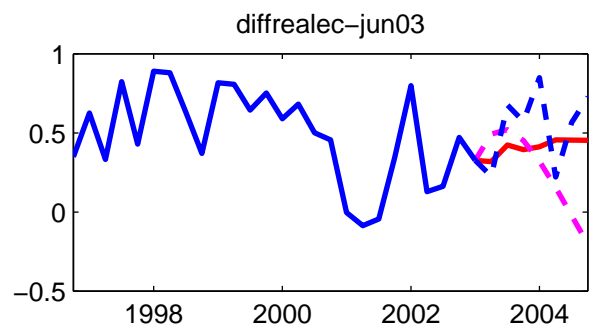
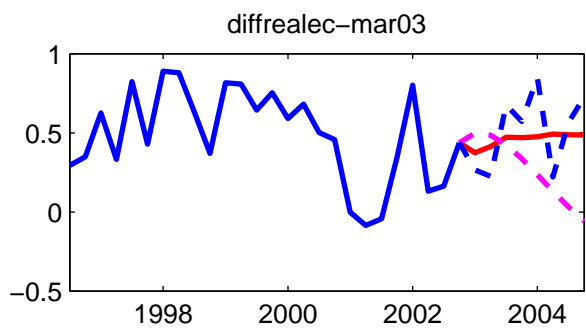
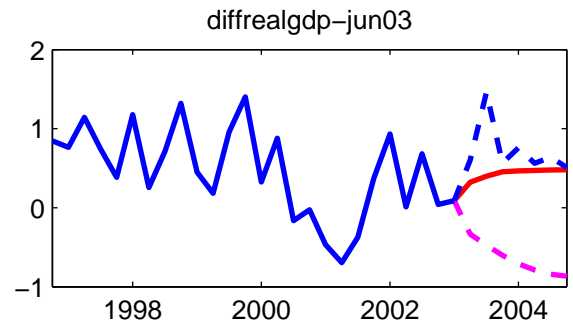
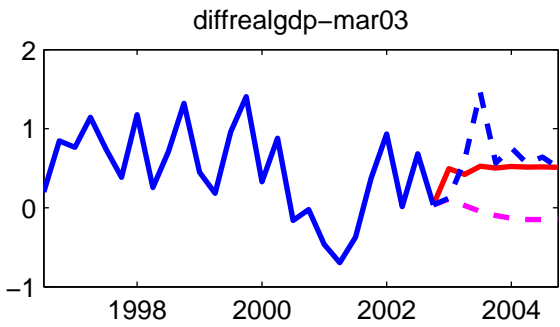
— BVAR  
 - - DSGE  
 — RT data  
 - - Final obs







- BVAR
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- - DSGE  
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