Structural Change and Monetary Policy
Recent Changes in Trend and Cycle

Comments by Mark W. Watson

I will use my time to discuss changes in both the cyclical and trend behavior of real GDP.

Cycle

Figure 1 plots annual changes in real GDP, the Federal Funds rate and 10-year Treasury Bond rates from 1960:1 through 1999:3. I have masked the period of interest rate volatility 1979:4-1983:4 to highlight differences between the early sample period, 1960-1979, and the recent period, 1984-1999. Panel A shows that GDP was less volatile in the 1984-99 period than in the 1960-79 period. The standard deviation of annual GDP growth rates fell from 2.4% in the early period to 1.6% in the recent period. (Summary statistics are given in Table 1.) Panel B shows that changes in the Federal Funds rate have also become less volatile: the standard deviation has fallen from 2.2% (220 basis points) to 1.4% (140 basis points). On the other hand, long term interest rates have become more volatile: the standard deviation of changes in 10-year Bond rates has increased from 0.6% (60 basis points) to 1.3% (130 basis points).

What is the connection between these volatility changes, and does it have anything to do with changes in monetary policy? To answer this question it is useful to put some structure on the covariation between the series. Consider the equations:

(1.1) $y = -\phi RL + \epsilon$

(1.2) $RF = \gamma y + \mu$

(1.3) $RL = \lambda RF + \beta y + \eta$

where y denotes GDP, RF denotes the Federal Funds rate and RL denote the 10-year Treasury Bond rate. Interpret (1.1) as an IS relation, (1.2) as a policy reaction function and (1.3) as a term structure equation. The terms $\epsilon$, $\mu$ and $\eta$ are the shocks to these relations. I have estimated the parameters of these equations over the early and late sample periods using the annual growth rates for y, RF and RL. While there are obvious problems with this approach (inflation is absent, no distinction is made between levels and changes, dynamics are ignored, etc.), the resulting parameter estimates give important clues about potential causes for the changes in the variability of the series.

Equations (1.1)-(1.3) contain 7 parameters ($\phi$, $\gamma$, $\lambda$, $\beta$, $\sigma_\epsilon$, $\sigma_\mu$, $\sigma_\eta$) and the covariance matrix of (y,RF,RL) contains only 6 unique elements. To identify the model, I have used a fixed value of $\phi$, since this parameter is the most likely to be constant across the two time periods. Since I was unsure about the correct value of $\phi$, I show results for values of $\phi$ ranging from 0.5 to 8.0. (Note: All variables are measured in percentage points at annual rates.)

The point estimates of the parameters are summarized in Table 2. Each column of the table shows estimates of the model's parameters for an assumed value of $\phi$, and the rows show results for the different sample periods. There are three results that are robust across all of the values of $\phi$. First, the estimate of $\gamma$ is larger in the second sample period, so that the Federal Funds rate responded more aggressively to increases in output during 1984-99 that during 1960-79. This is consistent with empirical results reported in Clarida, Gali and Gertler (1999) and Boivin (1999). Second, Federal Funds shocks were smaller in the latter period ($\sigma_\mu$ is much smaller in 1984-99 than in 1960-79) and long-rate shocks were larger ($\sigma_\eta$ increased). Estimates of changes in the variability of $\epsilon$ depend on the value $\phi$. If $\phi$ is small, then the point estimate of $\sigma_\epsilon$ is somewhat lower in the second sample period than in the first period; if $\phi$ is large, then there is a large increase in the estimated value of $\sigma_\epsilon$ in the second sample period. The third robust result is that the values of $\lambda$ and $\beta$ are much higher in the 1984-99 period than in the earlier period. Evidently, long-rates respond much more to changes in short rates and output now that they did during the 1960's and 1970's.

Table 3 investigates which of the parameter changes has the largest effect on output variability. The table shows the implied standard deviation of annual changes in GDP for different sets of parameter values. Two values of $\phi$ are considered, and for each value of $\phi$, results are shown for innovation standard deviations ($\sigma_\epsilon$, $\sigma_\mu$, $\sigma_\eta$), Federal Funds feedback coefficient ($\gamma$) and long-rate feedback coefficients ($\lambda$,$\beta$) computed over the two different sample periods. For example, looking at the block of results with $\phi=1$, the first row shows the implied standard deviation of output growth rates that results when all parameter values take on their values estimated during the first sample period. The value is 2.4%, which is the actual sample standard deviation of y over this sample period. The next row shows the implied standard deviation of y when $\lambda$ and $\beta$ take on the values estimated during the second sample period, but the other parameters take on values that were estimated during the first sample period. Now the standard deviation falls to 1.7%, which is very close to the actual second period value of 1.6%. Looking across all of the entries in the table, it is clear that the reduced variability in y is associated with changes in the behavior of long-rates through the coefficients $\lambda$ and $\beta$;

changes in the variability of shocks or the affect of output on Federal Funds have little effect on the variability of y.

Why has the behavior of long-rates changed? Changes in the behavior of short-rates provide the most obvious set of answers. Some change in short rate behavior is evident from table 2 since the estimated value of $\gamma$ increased in the second sample period. But the increase in $\gamma$ is relatively small and by itself cannot explain much of the increased variability in long rates. A more important change is an increase in the persistence of changes in the Federal Funds rate. Small changes in persistence of the short-rate process can lead to large changes in the behavior of expected future short rates, and hence to large changes in long-rates. In Watson (1999) I show that estimates of the largest univariate autoregressive root in the Federal Funds process increased from 0.96 during 1966-79 to 1.00 during 1985-98. As it turns out, this increase in persistence can explain all of the increased variability of long-rates over the sample period using a simple present value model linking long-rates and short-rates. Piazzesi (1999) finds an further increase in the persistence of the Federal Funds rate in 1994.

To get a clearer idea of the change in the short-rate process I have estimated a small vector autoregression including the logarithm of GDP, Federal Funds and 10-Year Treasury Bonds. I estimated the VAR over 1960-79 and 1984-99 sample periods. The VAR was specified using levels of all of the series and included a constant and 4 lagged values of the variables. To identify the VAR I used equations (1.1)-(1.3), but now applied to 1-quarter ahead forecast errors. Figure 2 shows the implied impulse responses for the Federal Funds rate over the two sample periods. (These results are for the model with $\phi=0$.) The solid lines in the figure show the impulse responses for the first period and the dashed lines show the results for the second period. The effect of output shocks ($\epsilon$) on the Federal Funds rate is somewhat larger in the second period, but much more persistent. The effect of short-rate shocks ($\mu$) is smaller, but much more persistent. There is little change in the estimated effect of long-rate shocks ($\eta$).

Taken together, these results suggest that changes in monetary policy are partly responsible for the decreased variability in output. Importantly, the change that seems most important is the increased persistence in changes in the Federal Funds rate. This increased persistence has led to increased variability in long-term rates, which in turn have helped dampen the cyclical variability in output. Welfare consequences of this kind of change in policy are discussed in Woodford (1999).

## Trend

Figure 4 plots quarterly changes in the logarithm of real GDP (shown in percentage points at an annual rate). Changes in the trend of GDP correspond to changes in the mean level of the series plotted in the figure. Since the series is "noisy" it is difficult to determine whether the mean has shifted, and if so, by how much.

To more formally make the same point, consider the equations

(2.1) $$\Delta y_t = \mu_t + c_t$$

(2.2) $$\mu_t = \mu_{t-1} + \eta_t$$

(2.3) $$\phi(L)c_t = \epsilon_t$$

where $\Delta y$ denote the growth rate of real GDP, $\mu$ denotes the average value of $\Delta y$, and c denotes the cyclical component. The cyclical component is allowed to follow a stationary autoregressive process given by (2.3). The only change from the standard representation of GDP is that the mean value $\mu$ is allow to vary through time, with variation governed by the variance of the noise component $\eta$. If $\sigma_\eta=0$, then $\mu_t=\mu_{t-1}=\mu$ and so there is no time variation. On the other hand, if $\sigma_\eta$ is large, then there is large time variation in $\mu_t$.

Table 4 presents several statistics that summarize information about the value of $\sigma_\eta$ for the real GDP data. Specifically, five different test statistics were computed to test the null hypothesis that $\sigma_\eta=0$. The second column of the table gives the p-value for each test. The p-values are all in the range of 0.4 to 0.5, so that the null hypothesis of no time variation in $\mu$ cannot be rejected. But, $\sigma_\eta=0$ is not the only value of $\sigma_\eta$ that is consistent with the data, and the third column shows the 95% confidence interval for $\sigma_\eta$ computed from each of the test statistics. The confidence intervals are very wide, including values of $\sigma_\eta$ greater than 0.4%. This confidence interval formalizes the uncertainty in the trend that is evident from looking at figure 4.

The next column gives an estimate of $\sigma_\eta$ computed using methods described in Stock and Watson (1998); these estimates range from 0.00 to 0.07 depending on the statistic used. To put these estimates in perspective, the final column presents estimates of the implied standard deviation of the change in $\mu$ over the sample period using these values of $\sigma_\eta$. These values range from 0.0 to 0.9%. Using the larger value would imply that changes in $\mu$ of $\pm 1\%$ would not be uncommon over a 30 year period.

While Table 4 gives estimates of expected variation in $\mu$ over the entire sample period, it is also interesting to know the time path of $\mu$. For given values of the parameters, the $\mu_t$ realization can be estimated by the Kalman smoother. Figures 3 and 4 show these estimated time paths of $\mu$ for six values of $\sigma_\eta$ ranging from 0.00 to 0.16. For each value of $\sigma_\eta$, the other parameters were estimated by Gaussian maximum likelihood. Figure 3 plots the estimated values of $\mu$ together with the $\Delta y$. Variation in $\Delta y$ dominates the plot. Figure 4 plots the estimated values of $\mu$ on a finer scale. Larger value of $\sigma_\eta$ imply larger variation in $\mu_t$, and the variability of the estimated values of $\mu$ are increasing in the value of $\sigma_\eta$ used for estimation. Thus the most variable series shown in figure 4 is the estimated value of $\mu_t$ using $\sigma_\eta$=0.16 and the least variable uses $\sigma_\eta$=0.0.

Table 5 shows estimates of $\mu_{1993:1}$ and $\mu_{1999:3}$ constructed for different assumed values of $\sigma_\eta$. Larger values of $\sigma_\eta$ imply larger estimated changes in the $\mu$ from 1993 and 1999. For example, when $\sigma_\eta$=0.04, the estimated change in $\mu_t$ is only .01%, but when $\sigma_\eta$=0.16, the estimated change is .18%. However, as $\sigma_\eta$ grows, so does the uncertainty associated with the estimated changes in $\mu$. This is shown in the last column which gives the standard error of $\hat{\mu}_{1993:1}-\hat{\mu}_{1999:3}$. When $\sigma_\eta$=.16, the standard error of the estimated change in very large: 0.77%.

In summary, it is difficult to say much about changes in the average rate of growth of GDP using data on GDP alone. The data from 1960-1999 are consistent with a constant mean, but also with a highly variable trend. The estimated trend growth rate over the past 6 years has changed little, but the standard error associated with this estimate is very large.

## References

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Woodford, Michael (1999), "Policy Inertia," manuscript, Princeton University.

Table 1
Standard Deviation of Annual Changes
(Percentage Points at Annual Rates)

| Series | 1960:1-1979:3 | 1984:1-1999:3 |
|---|---|---|
| Real GDP | 2.4 | 1.6 |
| Federal Funds Rate | 2.2 | 1.4 |
| 3 Month T-Bill Rate | 1.4 | 1.3 |
| 1 Year T-Bond Rate | 1.3 | 1.4 |
| 5 Year T-Bond Rate | 0.8 | 1.4 |
| 10 Year T-Bond Rate | 0.6 | 1.3 |

Notes: For Real GDP the entries are the standard deviation of $100 \times \ln(GDP_t/GDP_{t-4})$ where $GDP_t$ is the quarterly value of GDP. For the interest rates the entries are the standard deviations of $R_t - R_{t-4}$, where $R_t$ is the daily average interest rate in quarter t.

Table 2
Estimated Parameters For the Model

$$y = -\phi RL + \epsilon$$
$$RF = \gamma y + \mu$$
$$RL = \lambda RF + \beta y + \eta$$

| Parameter | Sample Period | ϕ 0.5 | 1.0 | 2.0 | 4.0 | 6.0 | 8.0 |
|---|---|---|---|---|---|---|---|
| $\gamma$ | 60-79 | 0.44 | 0.50 | 0.61 | 0.84 | 1.06 | 1.27 |
| $\gamma$ | 84-99 | 0.56 | 0.67 | 0.81 | 0.99 | 1.09 | 1.16 |
| $\lambda$ | 60-79 | 0.18 | 0.19 | 0.21 | 0.27 | 0.33 | 0.38 |
| $\lambda$ | 84-99 | 0.50 | 0.58 | 0.73 | 0.93 | 1.04 | 1.11 |
| $\beta$ | 60-79 | -0.04 | -0.02 | 0.01 | 0.04 | 0.03 | 0.02 |
| $\beta$ | 84-99 | 0.27 | 0.36 | 0.43 | 0.44 | 0.42 | 0.40 |
| $\sigma_\epsilon$ | 60-79 | 2.45 | 2.51 | 2.75 | 3.52 | 4.50 | 5.58 |
| $\sigma_\epsilon$ | 84-99 | 1.91 | 2.37 | 3.48 | 5.92 | 8.44 | 10.99 |
| $\sigma_\mu$ | 60-79 | 1.99 | 2.00 | 2.06 | 2.27 | 2.58 | 2.93 |
| $\sigma_\mu$ | 84-99 | 1.31 | 1.35 | 1.43 | 1.57 | 1.67 | 1.74 |
| $\sigma_\eta$ | 60-79 | 0.52 | 0.52 | 0.55 | 0.63 | 0.70 | 0.75 |
| $\sigma_\eta$ | 84-99 | 1.10 | 1.18 | 1.33 | 1.50 | 1.59 | 1.64 |

Notes: Entries are the estimated values of the parameters constructed over the sample periods shown in the second column. The variables y, RF and RL are the annual changes in GPD, the Federal Funds rate and the 10-Year Treasury Bond rate calculated as described in the note to table 1.

Table 3
Standard Deviation of GDP Growth Rates
Using Different Parameter Values

$$y = -\phi RL + \epsilon$$
$$RF = \gamma y + \mu$$
$$RL = \lambda RF + \beta y + \eta$$

| Parameter Value/Sample Period | | | | |
|---|---|---|---|---|
| $\phi$ | $\sigma_e, \sigma_\mu, \sigma_\eta$ | $\gamma$ | $\lambda, \beta$ | Standard Deviation of y |
| 1.0 | 60-79 | 60-79 | 60-79 | 2.4 |
| 1.0 | 60-79 | 60-79 | 84-99 | 1.7 |
| 1.0 | 60-79 | 84-99 | 60-79 | 2.4 |
| 1.0 | 60-79 | 84-99 | 84-99 | 1.6 |
| 1.0 | 84-99 | 60-79 | 60-79 | 2.5 |
| 1.0 | 84-99 | 60-79 | 84-99 | 1.7 |
| 1.0 | 84-99 | 84-99 | 60-79 | 2.4 |
| 1.0 | 84-99 | 84-99 | 84-99 | 1.6 |
| | | | | |
| 4.0 | 60-79 | 60-79 | 60-79 | 2.4 |
| 4.0 | 60-79 | 60-79 | 84-99 | 1.6 |
| 4.0 | 60-79 | 84-99 | 60-79 | 2.3 |
| 4.0 | 60-79 | 84-99 | 84-99 | 1.5 |
| 4.0 | 84-99 | 60-79 | 60-79 | 4.2 |
| 4.0 | 84-99 | 60-79 | 84-99 | 1.7 |
| 4.0 | 84-99 | 84-99 | 60-79 | 3.9 |
| 4.0 | 84-99 | 84-99 | 84-99 | 1.6 |

Note: The last column shows the implied standard deviation annual real GDP growth rates using the value of $\phi$ shown in the first column and the values of the estimated other parameter values taken from table 2 for the sample periods shown columns 2-4.

Table 4
Time Variation in GDP Trend Growth Rate

$$\Delta y_t = \mu_t + c_t$$

$$\mu_t = \mu_{t-1} + \eta_t$$

$$\phi(L)c_t = \epsilon_t$$

| Test Statistic | P-Value | $\sigma_\eta$ 95% CI | $\hat{\sigma}_\eta$ | $SD(\mu_{1999}-\mu_{1960})$ |
|---|---|---|---|---|
| Nyblom | 0.47 | 0.00 - 0.42 | 0.03 | 0.38 |
| Mean-Wald | 0.47 | 0.00 - 0.43 | 0.03 | 0.38 |
| Exp-Wald | 0.43 | 0.00 - 0.46 | 0.05 | 0.63 |
| Sup-Wald | 0.40 | 0.00 - 0.47 | 0.07 | 0.89 |
| POI7 | 0.51 | 0.00 - 0.37 | 0.00 | 0.00 |

Notes: The statistics are the Nyblom L-statistic, and the Mean, Exponential and Sup Wald statistics for a single break in the mean computed over the middle 70% of the sample. POI7 is the asymptotically point-optimal invariant test for testing $H_o:\sigma_\eta=0$ vs. $H_a:\sigma_\eta=7/T$. The column labeled $\hat{\sigma}_\eta$ is an estimate of $\sigma_\eta$ using the asymptotically median unbiased estimator in Stock and Watson (1998).

Table 5
Estimates of Trend GDP Growth Rates

$$\Delta y_t = \mu_t + c_t$$

$$\mu_t = \mu_{t-1} + \eta_t$$

$$\phi(L)c_t = \epsilon_t$$

| $\sigma_\eta$ | $\hat{\mu}_{1993:1}$ | $\hat{\mu}_{1999:3}$ | $\hat{\mu}_{1999:3}-\hat{\mu}_{1993:1}$ | $SE(\hat{\mu}_{1999:3}-\hat{\mu}_{1993:1})$ |
|---|---|---|---|---|
| 0.00 | 3.45 | 3.45 | 0.00 | 0.00 |
| 0.02 | 3.45 | 3.45 | 0.00 | 0.10 |
| 0.04 | 3.41 | 3.42 | 0.01 | 0.21 |
| 0.08 | 3.32 | 3.36 | 0.04 | 0.41 |
| 0.12 | 3.24 | 3.34 | 0.10 | 0.60 |
| 0.16 | 3.18 | 3.36 | 0.18 | 0.77 |

Notes: $\hat{\mu}_t$ is the estimate of $\mu_t$ computed using a Kalman smoother using data from 1960:1-1999:3, with $\sigma_\eta$ given in column 1 and the other model parameters estimated by Gaussian MLE conditional on this value of $\sigma_\eta$. The final column gives the estimated standard deviation of $\hat{\mu}_{1999:3}-\hat{\mu}_{1993:1}$ computed by the Kalman smoother.

Figure 1: Annual Differences

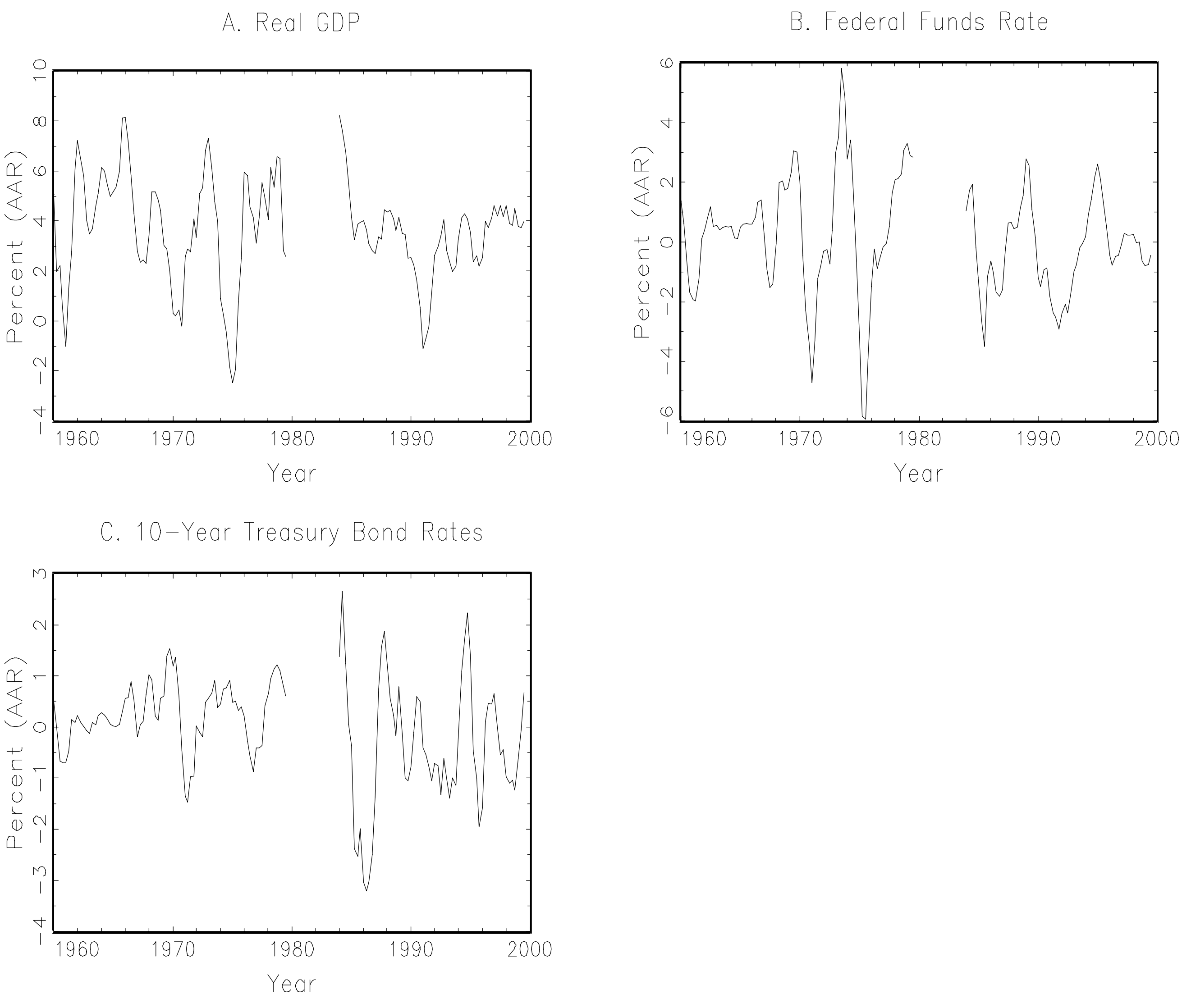

Figure 2: Impulse Response of Federal Funds Rate
(Response to a 1 Standard Deviation Shock)

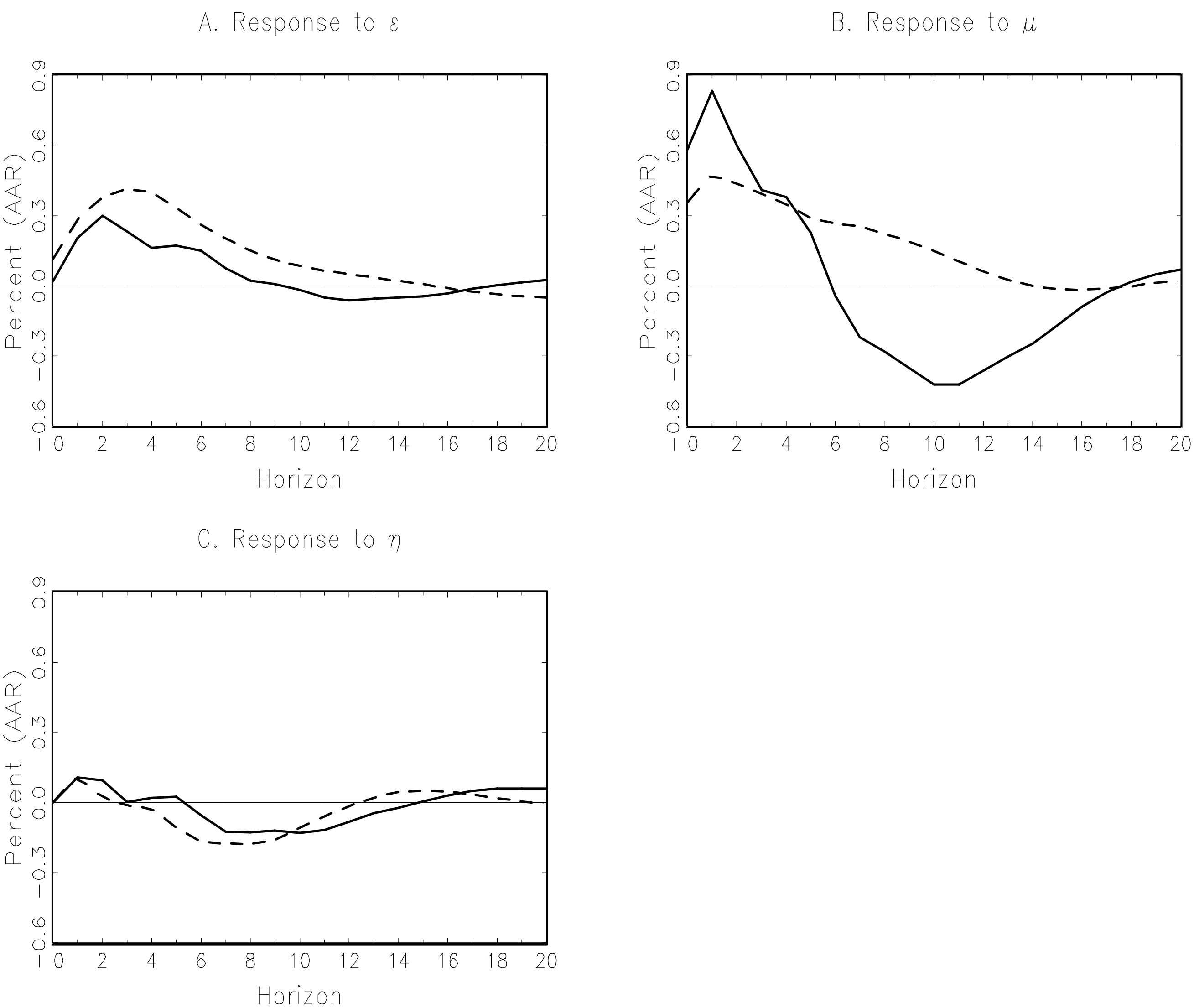

Figure 3
GDP Growth Rate

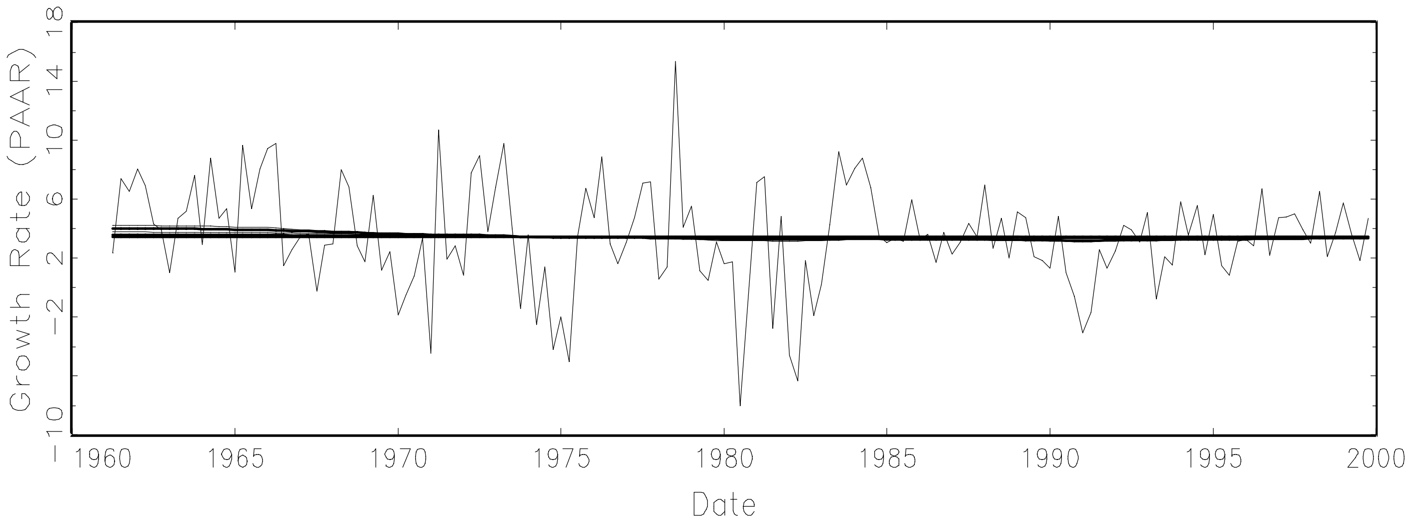


Figure 4
GDP Trend Growth Rates
(for different values of $\sigma_\eta$)