

# Evaluation of the Survey of Professional Forecasters in the Greenbook's Loss Function\*

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## Abstract

We aim to find a forecast in the Survey of Professional Forecasters (SPF) that is closest to the Greenbook forecast of the Federal Reserve Board. To do it, we look for an SPF cross-sectional percentile that is not encompassed by the Greenbook forecast under the Greenbook's estimated asymmetric quadratic loss function with allowing asymmetry to be time-varying. To evaluate each SPF percentile in terms of the Greenbook's asymmetric quadratic loss function, we introduce the encompassing test for the asymmetric least square regression (Newey and Powell 1987). From the analysis of the U.S. quarterly real output and inflation forecasts over the past four decades, we find that almost all SPF percentiles are encompassed by the Greenbook forecast in full data period. However there is evidence in sub-periods that many SPF percentiles are not encompassed by Greenbook. Among them, the best SPF percentile that is not encompassed by Greenbook and is closest to Greenbook for real output growth forecast is near the median of the SPF percentiles, while the best SPF percentile for inflation forecast is far below the median in the left tail of the SPF cross-sectional distribution. It indicates that the common practice of using the SPF median can be misleading.

*Key Words:* Asymmetric least squares, Encompassing test, Estimating asymmetric quadratic loss function, Forecast averaging, Model averaging.

*JEL Classification:* C1, C2, C3, C4, C5

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# 1 Introduction

A key issue in economic decision-making is the accurate prediction of future economy. Among many U.S. forecasting projects the Greenbook (GB) project of the Federal Reserve Board is known for better forecast performance than others. Romer and Romer (2000) find that the Greenbook inflation forecast outperforms several other inflation forecasts made by private sectors. In their later research (Romer and Romer 2008), the Romers also show that the Greenbook forecast dominates the Federal Open Market Committee (FOMC) forecast in predicting inflation and unemployment rate. Furthermore, the Greenbook forecast is closely related to monetary policy. The common perception is that Greenbook has advantage in information regarding Fed's policy intention and will be used in policy-making process (Sims 2002, Faust and Wright 2009). This makes Greenbook useful for economic decision-making since it may reveal the future path of monetary policy.

However, Greenbook is released with a five year lag, which prevents private sectors from taking advantage of it. It is therefore desirable to have an alternative forecast that best proxies the Greenbook forecast. In this paper we try to find the best proxies for Greenbook from the cross-sectional percentiles of the Survey of Professional Forecasters (SPF).<sup>1</sup> The SPF forecasts are made by forecasters that largely come from the business/finance world. Zarnowitz and Braun (1993) find that the SPF forecast significantly outperforms many econometric and time series forecasting models. Different from many forecast projects that report only one point forecast each time, the SPF contains a survey of multiple forecasts at each time. The cross-sectional distribution among different SPF forecasters provides a large set of alternative forecasts from which a good Greenbook substitute may be found.

In the literature, Romer and Romer (2000) are the first who compare the performance of the Greenbook forecast and SPF forecasts. They find that the Greenbook inflation forecast strictly dominates SPF's median inflation forecast, which has been further examined in depth by Rossi and Sekhposyan (2016). Romer and Romer (2000) use only the median of SPF forecasts while ignoring other percentiles. In fact, the median of SPF forecasts has been widely used to represent the whole cross-sectional distribution of the SPF forecasts, but it is not clear whether the median is superior

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<sup>1</sup>The SPF percentiles are formally defined in Section 3.1.

to other percentiles of the cross-sectional distribution of the SPF forecasts. Besides, the Romers' comparison is based on the mean squared error (MSE) loss that is symmetric. However, Capistran (2008) finds that the loss function of Greenbook is significantly asymmetric over certain periods. In these regards, our paper extends the Romers' (2000) study in two aspects, by comparing Greenbook with all the SPF percentiles and by allowing potential asymmetry in the criterion (loss) function for the comparison.

The goal of this paper is to search for the SPF percentiles that are *close* to Greenbook in forecasting real output growth and inflation. We measure the distance (how close is close enough) from the encompassing statistic between a SPF percentile and Greenbook. We formulate the encompassing statistic (see e.g., Harvey, Leybourne and Newbold 1998) based on the asymmetric least squares (ALS) regression (Newey and Powell 1987) in terms of Greenbook's loss function with its asymmetric extent estimated. We estimate the asymmetric quadratic loss for Greenbook by the GMM of Elliott, Komunjer and Timmermann (2005, EKT) and then we look for the best SPF percentile that is least encompassed by the Greenbook forecast under the estimated Greenbook's loss function.

We search the individual forecasts in the SPF to see which percentile of the SPF forecasters produces a forecast similar to the forecasts in Greenbook. This could be useful because Greenbook is not made public for five years, whereas SPF is produced every quarter. We use data from SPF to find the percentiles of the SPF forecast distribution (cross-sectional at each time) that most closely represent forecasts from the Greenbook forecasts. The motivation is that the Greenbook forecasts are especially good on forecasting inflation and nowcasting real output growth, and since they are conditioned on a monetary policy assumption, the forecasts help reveal underlying policy assumptions. Since the GB forecasts are available only with a five year lag, analysts who are interested in a more current approximation of the Greenbook forecast may then be interested in using the SPF forecast distribution to infer the current GB forecast.<sup>2</sup>

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<sup>2</sup>We consider SPF as a reasonable collection of forecasts alternative to Greenbook. One may wonder why we choose SPF as a collection of alternative forecasts to Greenbook. Another possibility can be the FOMC forecasts published in Monetary Policy Report of the FRB. The FOMC forecasts from this report have been compared to the Greenbook forecasts and SPF forecasts by Gavin and Pande (2008) and Romer and Romer (2008). The upside is that the FOMC forecasts are constructed after actually seeing the Greenbook numbers and hence there is a reason to expect that the FOMC forecasts can be good alternative forecasts to Greenbook because Greenbook will become

From the analysis of the U.S. quarterly real output and inflation forecasts over the past four decades, we find that almost all the SPF percentiles are encompassed by the GB forecast (i.e., SPF does not meaningfully contribute to a combined forecast of the GB and SPF as GB dominates SPF in forecasting quality) in full data period especially for inflation forecast. This result shows that the GB forecast has information advantage against almost all percentiles of the SPF forecast, especially in forecasting inflation. However there is evidence in sub-periods that many SPF percentiles are not encompassed by GB. Among the SPF percentiles that are not encompassed by GB, the best SPF percentile is found near the median (or above the median in recent years) for real output growth forecast, but it is in the lower percentiles far below the median for the inflation forecast. We find that over a sample period from 1968Q4 to 2006Q4 for inflation forecasts, the GB forecast largely “encompasses” the SPF forecasts, although for sub-samples of the data this needs not be the case. For the post 2000 data the SPF percentiles in the tail are not encompassed by the GB and the best SPF percentile is found near the 13th percentile. Thus, using the median SPF inflation forecast to approximate the GB over that period would lead to over-prediction. It indicates that the common practice of using the SPF median can be misleading for inflation forecast and better SPF percentiles can be found from using the procedure proposed in this paper. Of note, we do not assume a symmetric loss function for the FRB who produces the GB forecasts when conducting the forecast comparisons. We instead estimate an asymmetric loss function on real output growth and inflation.

The paper is organized as follows. Section 2 presents the estimation of the Greenbook’s loss function. Section 3 presents the encompassing results of comparing the SPF percentiles with Greenbook under the estimated Greenbook’s loss function. Section 4 concludes. Section 5 explains how we estimate the encompassing statistic and its asymptotic standard error from the asymmetric least regression under the estimated Greenbook’s loss function.

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available with 5 year lag. However, a downside is that the FOMC forecasts have been available only twice a year until very recently. Both Greenbook and SPF are available in quarterly frequency. Gavin and Pande (2008) compare the relative forecast accuracy of the FOMC and SPF forecasts for output growth and inflation and find the differences are negligible.

## 2 Estimating Greenbook Forecast’s Loss Function

The Greenbook forecast is prepared by the FRB before each FOMC meeting. There are typically two forecasts per quarter, one made in the first month of each quarter and the other made in the last month of each quarter, but we choose the former to be our Greenbook forecast in evaluation of the SPFs.<sup>3</sup> We use annualized quarter-over-quarter growth rates of both real GNP/GDP forecast (real output forecast) and GNP/GDP deflator forecast (inflation forecast).<sup>4</sup> Both one-quarter-ahead ( $h = 1$ ) forecast and one-year-ahead ( $h = 4$ ) forecast are included to check whether the forecast horizon affects our results. One-quarter-ahead forecasts are available for the period 1968Q4 – 2006Q4, and one-year-ahead forecasts are available for the period 1974Q4 – 2006Q4. These sample periods will be referred to as “the full data period”. In this paper, real-time data is used as realized value for those variables of interest, because it contains fewer re-benchmarking and definitional changes compared to the revised data which uses the latest vintage (Croushore and Stark 2001).

In this section, under the assumption that the Greenbook loss function is quadratic and possibly asymmetric, we estimate the extent of the asymmetry. Subsection 2.1 briefly introduces the EKT methodology for the estimation. Subsection 2.2 presents the estimation results of Greenbook’s loss function asymmetry.

### 2.1 The EKT Methodology

Assume that the  $h$ -step-ahead Greenbook forecast  $f_t$  for  $y_{t+h}$  is conditional on the information set  $\mathcal{F}_t$  at time  $t$  and adopts the following loss function

$$L(f_t; \alpha) = [\alpha + (1 - 2\alpha) \cdot 1(e_t < 0)] \cdot |e_t|^p, \tag{1}$$

where  $e_t \equiv y_{t+h} - f_t$ ,  $1(\cdot)$  is the indicator function and  $\alpha \in (0, 1)$ .  $p$  determines the shape of the loss function and is fixed at  $p = 2$  throughout our analysis.<sup>5</sup>

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<sup>3</sup>The SPF forecast is made during the second month of each quarter. Therefore, the last-month Greenbook forecast is not a proper benchmark for the SPF forecast, since it may have the SPF forecast in their information set.

<sup>4</sup>The forecasts were for growth of GNP and GNP price index before 1992 and for GDP and GDP price index afterwards.

<sup>5</sup>As noted in Section 3.2 we considered both  $p = 1, 2$ . As the results are similar we focus on  $p = 2$  for presentation. Regression with the loss function (1) with  $p = 2$  is the expectile regression of Newey and Powell (1987). When  $p = 1$ , the regression is quantile regression of Koenker and Bassett (1978).

We adopt the EKT method to estimate  $\alpha$  of the Greenbook's loss function. For a given (unknown) parameter  $\alpha$ , we also assume the Greenbook forecast  $f_t = \theta'W_t$  is linear in  $W_t \in \mathcal{F}_t$  with  $\theta \in \Theta \subset \mathbb{R}^k$  satisfying

$$\min_{\theta} E(L(f_t; \alpha)). \quad (2)$$

The first-order condition implies the orthogonality condition

$$E(W_t \cdot [1(e_t < 0) - \alpha] \cdot |e_t|) = 0, \quad (3)$$

and the second-order condition can be verified (EKT, p. 1121).

Under proper assumptions,  $\theta(\alpha)$  is a one-to-one mapping from  $(0, 1)$  to the parameter space  $\Theta$ . This one-to-one relation enables us to back out the parameter  $\alpha$  from  $f_t$ . However,  $W_t$ , the information set of the producer (the FRB) of Greenbook is not available to us (a user of the Greenbook). So we use an  $m$ -vector instrument  $V_t$  to estimate the scalar  $\alpha$ . Results presented in this paper are computed using the instruments  $V_t = (1, y_{t-1})'$  of a constant and the lagged realized value with  $m \equiv \dim(V_t) = 2$ .<sup>6</sup>

If  $V_t \subset W_t$ , then the orthogonality condition with the instruments can be written as

$$A(f_t; \alpha) := E(V_t \cdot [1(e_t < 0) - \alpha] \cdot |e_t|) = 0. \quad (4)$$

Let  $\alpha_0$  be the unique minimum of the weighted quadratic distance

$$\alpha_0 := \arg \min_{\alpha} Q(f_t; \alpha) = A(f_t; \alpha)' \cdot S^{-1} \cdot A(f_t; \alpha), \quad (5)$$

where  $S$  is a positive definite  $m \times m$  weight matrix. Let  $B(f_t) := E(V_t \cdot |e_t|)$  and  $C(f_t) := E(V_t \cdot 1(e_t < 0) \cdot |e_t|)$ . Notice that  $A(f_t; \alpha) = C(f_t) - \alpha B(f_t)$ . Hence,  $Q(f_t; \alpha)$  is a quadratic equation in  $\alpha$ .

Taking the first derivative of  $Q(f_t; \alpha)$  with respect to  $\alpha$ , we obtain  $\alpha_0$  as

$$\alpha_0 = \frac{B(f_t)' S^{-1} C(f_t)}{B(f_t)' S^{-1} B(f_t)}. \quad (6)$$

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<sup>6</sup>A larger set of instruments can certainly be possible as long as all instruments are strongly valid (exogenous). In this paper, we have reported the result using the simplest choice of instrument  $V_t = (1, y_{t-1})'$  with only one lagged  $y_{t-1}$ . More lags and other variables that are believed to be exogenous may be included in the instrument  $V_t$ . Our empirical results were robust to various other choices ( $V_t$ ) of the instruments and different number ( $m$ ) of instruments.

Given the forecast vector  $\mathbf{f} := (f_1 \dots f_T)'$ ,  $\alpha_0$  is consistently estimated by  $\hat{\alpha}_T(\mathbf{f})$ ,

$$\hat{\alpha}_T(\mathbf{f}) = \frac{\hat{B}'_T(\mathbf{f}) \hat{S}_T^{-1}(\mathbf{f}; \alpha) \hat{C}_T(\mathbf{f})}{\hat{B}'_T(\mathbf{f}) \hat{S}_T^{-1}(\mathbf{f}; \alpha) \hat{B}_T(\mathbf{f})}, \quad (7)$$

where  $\hat{B}_T(\mathbf{f}) := \frac{1}{T} \sum_{t=1}^T V_t \cdot |e_t|$  and  $\hat{C}_T(\mathbf{f}) := \frac{1}{T} \sum_{t=1}^T V_t \cdot 1(e_t < 0) \cdot |e_t|$ . The estimation of  $S$  uses Newey and West's (1987) method.<sup>7</sup> EKT (2005) show that this estimator is consistent and asymptotic normal, conditional on the observed forecast vector  $\mathbf{f}$ ,

$$\sqrt{T} \hat{G}_T^{-1/2}(\mathbf{f}; \alpha) (\hat{\alpha}_T(\mathbf{f}) - \alpha_0) \Big| \mathbf{f} \xrightarrow{d} N(0, 1), \quad (8)$$

where  $\hat{G}_T(\mathbf{f}; \alpha) := \left[ \hat{B}'_T(\mathbf{f}) \hat{S}_T^{-1}(\mathbf{f}; \alpha) \hat{B}_T(\mathbf{f}) \right]^{-1}$ .

Moreover, when more number of instruments are used than the number of parameter to estimate, i.e.,  $m > 1$ , the over-identification test can be served as a diagnostic check for the adequacy of the estimated asymmetry conditional on the observed forecast series  $\mathbf{f}$ . This is to test whether the estimated asymmetry  $\hat{\alpha}_T(\mathbf{f})$  satisfies the moment condition in (4) by the following statistic

$$J_T(\mathbf{f}; \hat{\alpha}_T(\mathbf{f})) := T \times \hat{A}_T(\mathbf{f}; \hat{\alpha}_T(\mathbf{f}))' \hat{S}_T^{-1}(\mathbf{f}; \hat{\alpha}_T(\mathbf{f})) \hat{A}_T(\mathbf{f}; \hat{\alpha}_T(\mathbf{f})), \quad (9)$$

where  $\hat{A}_T(\mathbf{f}; \hat{\alpha}_T(\mathbf{f})) := \hat{C}_T(\mathbf{f}) - \hat{\alpha}_T(\mathbf{f}) \hat{B}_T(\mathbf{f})$ . Under the null hypothesis  $H_0 : A(f_t; \alpha_0) = 0$ , the statistic  $J_T(\mathbf{f}; \hat{\alpha}_T(\mathbf{f}))$  follows the asymptotic  $\chi^2$  distribution with  $(m - 1)$  degrees of freedom.

Additionally, with a fixed value  $\alpha = \alpha_1$ , the following statistic

$$J_T(\mathbf{f}; \alpha_1) = T \times \hat{A}_T(\mathbf{f}; \alpha_1)' \hat{S}_T^{-1}(\mathbf{f}; \alpha_1) \hat{A}_T(\mathbf{f}; \alpha_1) \quad (10)$$

serves as a diagnostic check for the adequacy of the loss function with  $\alpha = \alpha_1$  conditional on the observed forecast series  $\mathbf{f}$ . Under the null hypothesis  $H_0 : A(f_t; \alpha_1) = 0$ , the statistic  $J_T(\mathbf{f}; \alpha_1)$  follows the asymptotic  $\chi^2$  distribution with  $m$  degrees of freedom.

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<sup>7</sup>The Newey and West estimator of  $S$  is  $\hat{S}_T(\mathbf{f}; \alpha) = T^{-1} \sum_{j=-4}^4 \omega_{|j|} \sum_{t=|j|}^T a(f_t; \alpha) a'(f_{t-|j|}; \alpha)$ , where  $a(f_t; \alpha) := V_t \cdot [1(e_t < 0) - \alpha] \cdot |e_t|$  and  $\omega_{|j|} = 1 - \frac{|j|}{5}$ . Because the computation of  $\hat{S}_T(\mathbf{f}; \alpha)$  depends on  $\alpha$ , we use iteration starting from  $\hat{S}_T(\mathbf{f}; \alpha) = I_m$  to compute the initial estimate  $\hat{\alpha}_{T,1}(\mathbf{f})$ , then plug it into  $\hat{S}_T(\mathbf{f}; \hat{\alpha}_{T,1}(\mathbf{f}))$  to get a more efficient weighting matrix  $\hat{S}_T^{-1}(\mathbf{f}; \hat{\alpha}_{T,1}(\mathbf{f}))$ , and use  $\hat{S}_T^{-1}(\mathbf{f}; \hat{\alpha}_{T,1}(\mathbf{f}))$  to compute a new estimate  $\hat{\alpha}_{T,2}(\mathbf{f})$ . These steps are repeated until convergence.

## 2.2 Estimation of Greenbook Loss Function: Results

Let  $\mathbf{f}^{GB} := (f_1^{GB} \dots f_T^{GB})'$  be the vector of Greenbook forecasts. Plugging  $\mathbf{f}^{GB}$  into equations (7), (8), (9), and (10), we estimate the Greenbook's loss function asymmetry  $\hat{\alpha}_T(\mathbf{f}^{GB})$ , its asymptotic standard error  $T^{-1/2} \hat{G}_T^{1/2}(\mathbf{f}^{GB}; \hat{\alpha}_T(\mathbf{f}^{GB}))$ , the diagnostic statistic  $J_T(\mathbf{f}^{GB}; \hat{\alpha}_T(\mathbf{f}^{GB}))$  for the adequacy of the estimated loss function for Greenbook forecast, and the diagnostic statistic  $J_T(\mathbf{f}^{GB}; \alpha_1 = 0.5)$  for the adequacy of the symmetric loss function for Greenbook forecast. Table 1 summarizes the estimation and test results in the full data period and three sub-periods: Before-1982, 1982-2000, and After-2000.<sup>8</sup>

*Table 1 About Here*

In full data period, for both real output growth forecast and inflation forecast, and for both short horizon forecast and long horizon forecast, the symmetric loss function seems to be adequate for Greenbook, because the point estimates of  $\hat{\alpha}_T(\mathbf{f}^{GB})$  are not significantly different from 0.5 according to their asymptotic standard errors reported in Column 3 of Table 1. This result is consistent with the diagnostic statistics  $J_T(\mathbf{f}^{GB}; 0.5)$ , whose asymptotic p-values reported in Column 5 are all too large to reject the adequacy of the symmetric loss for Greenbook.

However, for the three sub-periods, most estimates of the loss function parameter are significantly different from 0.5. In the sub-periods before 1982 and after 2000, the estimated loss function parameters are significantly larger than 0.5 for real output forecast, but are significantly lower than 0.5 for inflation forecast, especially for the long horizon  $h = 4$ . In the sub-period 1982-2000, the estimated loss function parameter are significantly smaller than 0.5 for real output growth forecast, but are significantly higher than 0.5 for inflation forecast. These significant asymmetry results for the three sub-periods are consistent with the diagnostic test results in Column 5.

The results in Column 4 supports the adequacy of the estimated loss function for Greenbook, with all  $p$ -values but one larger than 0.05. It is useful to note that the  $p$ -value of  $J_T(\mathbf{f}^{GB}; \hat{\alpha}_T(\mathbf{f}^{GB}))$  are uniformly larger than that of  $J_T(\mathbf{f}^{GB}; 0.5)$ , indicating that the estimated loss function using

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<sup>8</sup>This way of splitting the data is according to Capistran and Timmermann's (2009) finding that "the shift in the sign of the bias observed for a substantial portion of forecasters around 1982", and an apparent shift in the direction of Greenbook's loss asymmetry in both real output growth and inflation forecasts after 2000.



$\alpha = \hat{\alpha}_T(\mathbf{f}^{GB})$  is more adequate for Greenbook than fixing  $\alpha = 0.5$ , even for the full data period. Furthermore, the asymmetry exhibits a time-varying nature as shown in Column 3. Therefore, in the next section, in finding the SPF percentiles that are closest to Greenbook, we will use the estimated Greenbook’s loss function rather than using the loss function with  $\alpha = 0.5$  even for the full data period.

### 3 Comparing SPF Percentiles in Greenbook’s Loss Function

Now, we return to the goal of this paper, the search of SPF’s cross-sectional percentiles that are closest to the Greenbook, in the sense that they are not encompassed by Greenbook (in terms of the Greenbook’s estimated loss function which we have just obtained from the previous section). If we make economic decision based on the Greenbook forecast, we would be benefited from the FRB’s monetary policy since Greenbook is used in policy making. In reality Greenbook is available with a five year lag and thus we wish to see if there exists an SPF percentile that is similar to the Greenbook forecast. While the SPF-median has been widely used, it may not be the SPF percentile that resembles the Greenbook forecast most closely.

#### 3.1 SPF Percentiles

The Survey of Professional Forecasters is the oldest quarterly survey forecast in the United States. Unlike other forecast projects, the SPF contains a survey of different forecasts at each time. In order to evaluate forecast performance of different component forecasts in the SPF, we define the  $i$ th percentile of the SPF forecasts in a cross-sectional distribution of the SPF forecasts at time  $t$  ( $t = 1, 2, \dots, T$ ). Let  $n_t$  be the number of forecasts in the SPF at time  $t$ . The  $n_t$  cross-sectional SPF forecasts at time  $t$  are ordered from the smallest to the largest, and the  $i$ th percentile,  $f_t^{SPF(i)}$ ,  $i \in [0, 100]$ , is computed. The time series vector  $\mathbf{f}^{SPF(i)} := \left( f_1^{SPF(i)} \dots f_T^{SPF(i)} \right)'$  is the  $i$ th percentile forecast series (denoted  $SPF(i)$ ). Our goal is to find out a set of  $\{i\}$  such that  $\mathbf{f}^{SPF(i)}$  is not encompassed by the Greenbook forecast  $\mathbf{f}^{GB}$  in terms of the loss function  $L(\cdot; \alpha)$  in (1) with  $\alpha = \hat{\alpha}_T(\mathbf{f}^{GB})$  estimated in Table 1.<sup>9</sup>

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<sup>9</sup>We use the SPF forecast data in the same way as the Greenbook forecast as explained in the beginning of Section 2. We use the annualized SPF forecasts for quarter-over-quarter growth rate of real GNP/GDP and GNP/GDP

### 3.2 Encompassing Test for Comparing SPF Percentiles in Greenbook's Loss

To find which SPF-percentile is the closest to Greenbook, we examine which SPF-percentile is least encompassed by Greenbook. Consider a forecast averaging or a combined forecast (CF)

$$f_t^{CF(i)} := \left(1 - \lambda^{(i)}\right) f_t^{GB} + \lambda^{(i)} f_t^{SPF(i)}. \quad (11)$$

The combined forecast contains  $SPF(i)$  with the weight  $\lambda^{(i)}$  which may be either positive or negative. If  $\lambda^{(i)} = 0$ ,  $SPF(i)$  is encompassed by the Greenbook forecast. If  $\lambda^{(i)} < 0$ ,  $SPF(i)$  should go “short” in forming a portfolio of the two forecasts, in which case the combined forecast can still be better than the Greenbook forecast with shorting  $SPF(i)$  with a negative weight and thus  $SPF(i)$  is dominated by the Greenbook forecast. If  $\lambda^{(i)} > 0$ ,  $SPF(i)$  has some contribution to the combined forecast that is improved over Greenbook and thus  $SPF(i)$  is not encompassed by the Greenbook forecast. Our goal in this paper is to find the SPF percentile closest to Greenbook. We measure the closeness by using  $\lambda^{(i)}$ . The larger  $\lambda^{(i)}$  is, the closer  $SPF(i)$  is to Greenbook. Thus the best SPF-percentile is least encompassed by Greenbook, which is  $SPF(i)$  with the largest positive value of  $\lambda^{(i)}$ . Hence, we test the null hypothesis  $H_0 : \lambda^{(i)} = 0$  against the one-sided alternative hypothesis  $H_1 : \lambda^{(i)} > 0$ .

Define the forecast errors  $e_t^{GB} := y_{t+h} - f_t^{GB}$ ,  $e_t^{SPF(i)} := y_{t+h} - f_t^{SPF(i)}$ , and  $e_t^{CF(i)} := y_{t+h} - f_t^{CF(i)}$ . The equation (11) can be rewritten with the forecast errors as

$$e_t^{GB} = \lambda^{(i)} \left( e_t^{GB} - e_t^{SPF(i)} \right) + e_t^{CF(i)}. \quad (12)$$

The combination weight  $\lambda^{(i)}$  is estimated from

$$\lambda^{(i)} = \arg \min_{\lambda^{(i)}} E \left[ L \left( f_t^{CF(i)}; \hat{\alpha}_T(\mathbf{f}^{GB}) \right) \right] \quad (13)$$

where

$$L \left( f_t^{CF(i)}; \hat{\alpha}_T(\mathbf{f}^{GB}) \right) = \left[ \hat{\alpha}_T(\mathbf{f}^{GB}) + (1 - 2\hat{\alpha}_T(\mathbf{f}^{GB})) \cdot \mathbf{1} \left( e_t^{CF(i)} < 0 \right) \right] \cdot \left| e_t^{CF(i)} \right|^p. \quad (14)$$

deflator. Both one-quarter-ahead ( $h = 1$ ) and one-year-ahead ( $h = 4$ ) forecasts are used, and the data periods for both horizons are the same as those in Greenbook forecast.

<sup>10</sup>The quadratic loss function (14) with  $p = 2$  gives the expectile regression or the asymmetric least squares

Note that we evaluate  $SPF(i)$  relative to Greenbook under the Greenbook's loss function using the estimated loss parameter  $\hat{\alpha}_T(\mathbf{f}^{GB})$ . Thus  $\lambda^{(i)}$  depends on  $\hat{\alpha}_T(\mathbf{f}^{GB})$ .

Under the null hypothesis  $H_0 : \lambda^{(i)} = 0$ ,  $f_t^{GB}$  encompasses  $f_t^{SPF(i)}$ . It means that, under the Greenbook's loss function, the Greenbook forecast is superior to  $SPF(i)$  forecast, in the sense that if we have both of them at hand the best forecast combination is just the Greenbook forecast with zero weight to  $SPF(i)$ . If the null hypothesis is rejected in favor of the one-sided alternative  $H_1 : \lambda^{(i)} > 0$ ,  $SPF(i)$  can contribute to the forecast combination. Appendix shows how we estimate  $\hat{\lambda}_T^{(i)} := \hat{\lambda}_T^{(i)}(\hat{\alpha}_T(\mathbf{f}^{GB}))$  and its consistent asymptotic standard error  $SE(\hat{\lambda}_T^{(i)})$  by applying the method of asymmetric least squares regression. The 5% asymptotic critical value to test the null hypothesis  $H_0 : \lambda^{(i)} = 0$  against the one-sided alternative  $H_1 : \lambda^{(i)} > 0$  is then computed by  $C_T^{(i)} \equiv 1.645 \times SE(\hat{\lambda}_T^{(i)})$  for each  $i = 1, \dots, 100$ . If  $\hat{\lambda}_T^{(i)} > C_T^{(i)}$  for each percentile  $i = 1, \dots, 100$ , the null hypothesis that  $SPF(i)$  is encompassed by Greenbook ( $H_0 : \lambda^{(i)} = 0$ ) is rejected at 5% level in favor of the alternative hypothesis that  $SPF(i)$  is not encompassed by Greenbook ( $H_1 : \lambda^{(i)} > 0$ ).

### 3.3 Finding the Best SPF Percentile That Is Closest to Greenbook: Results

In our empirical results (Figures 1-4) we present  $\hat{\lambda}_T^{(i)}$  (solid black line) and  $C_T^{(i)}$  (dashed red line). Our goal is to find the SPF percentile closest to Greenbook with the largest value of  $\hat{\lambda}_T^{(i)}$ . Figure 1 summarizes the encompassing results for the full date period and Figures 2, 3, 4 for the three sub-periods (Before 1982, 1982-2000, After 2000) respectively.

*Figures 1-4 About Here*

For the **full data period** in Figure 1, we find the following.

1. For the real output growth forecast for both horizons  $h = 1, 4$ , while most SPF percentiles are encompassed by Greenbook, we find that the best SPF percentile, the percentile  $i$  with the largest estimated value of  $\lambda^{(i)}$ , is near the median as seen from Figure 1(a,b). The best

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regression of Newey and Powell (1987). While all the encompassing literature uses the symmetric squared forecast error loss, we use the asymmetric squared error loss. The forecast combination weights  $\lambda$  and  $(1 - \lambda)$  are then estimated from the encompassing test statistic. To the best of our knowledge this is new in the forecast encompassing literature. A special case when the expectile regression with  $\alpha = 0.5$  gives the encompassing result of the existing literature for the conditional mean regression.

SPF percentiles are found near the median (54th for  $h = 1$  and 41st for  $h = 4$ ). They have very large positive values of  $\hat{\lambda}_T^{(i)}$  significantly ( $h = 1$ ) and nearly significantly ( $h = 4$ ).

2. For the inflation forecast, all the SPF percentiles are encompassed by Greenbook for both  $h = 1, 4$ . This can be read from Figure 1(c,d) as  $\hat{\lambda}_T^{(i)}$  are near zero and  $\hat{\lambda}_T^{(i)} < C_T^{(i)}$  for all  $i$ . This finding confirms Romer and Romer (2000) who discovered Greenbook's information advantage over private sectors in forecasting inflation. The best SPF percentiles for inflation forecast are far away from the median and the point estimates  $\hat{\lambda}_T^{(i)}$  for inflation forecast are much smaller and virtually zero.
3. Greenbook's dominance over the SPF-percentiles is much more significant in inflation forecast than in real output growth forecast. Most SPF percentiles have the positive  $\hat{\lambda}_T^{(i)}$  for real output growth, but have virtually zero weight for inflation.

For the sub-period **Before-1982** in Figure 2, the encompassing results are more significant. We find the following.

1. For the real output growth forecast for both  $h = 1, 4$ , about an half of SPF percentiles below around the SPF-median are encompassed by Greenbook:  $\hat{\lambda}_T^{(i)} < C_T^{(i)}$  for  $i < 56$  in  $h = 1$  (Figure 2a), and  $\hat{\lambda}_T^{(i)} < C_T^{(i)}$  for  $i < 39$  in  $h = 4$  (Figure 2b). The remaining SPF percentiles above the SPF-median are not encompassed by Greenbook. The best SPF percentiles with the largest value of  $\hat{\lambda}_T^{(i)}$  are found near the median (Figure 2(a,b)) with significantly positive values of  $\hat{\lambda}_T^{(i)}$ .
2. For the inflation forecast for  $h = 1$ , all the SPF percentiles are encompassed by Greenbook (Figure 2(c)) with  $\hat{\lambda}_T^{(i)}$  near zero and insignificant ( $\hat{\lambda}_T^{(i)} < C_T^{(i)}$ ) for all  $i$ . This confirms Romer and Romer (2000) again. However, for inflation forecast for  $h = 4$ , SPF percentiles in the left tail are not encompassed by Greenbook ( $\hat{\lambda}_T^{(i)} > C_T^{(i)}$  for  $i < 35$ ) and the best SPF percentile is below the 20th percentile.
3. There are many SPF percentiles that are not encompassed by Greenbook. The best SPF percentiles are found near the SPF-median for the real output growth ( $h = 1, 4$ ) but they

are far below the SPF-median for inflation ( $h = 4$ ). Greenbook's dominance over the SPF-percentiles is significant only in inflation forecast with  $h = 1$  (Figure 2c).

For the sub-period **1982-2000** in Figure 3, we find the following.

1. For the real output growth forecast for both  $h = 1, 4$ , the best SPF percentiles with the largest  $\hat{\lambda}_T^{(i)}$  are near the median (Figure 3(a,b)). They have very large positive values of  $\hat{\lambda}_T^{(i)}$  significantly ( $h = 1$ ) or nearly significantly ( $h = 4$ ).
2. For the inflation forecast, all the SPF percentiles are encompassed by Greenbook for both  $h = 1, 4$ . This can be seen from Figure 3(c,d) as  $\hat{\lambda}_T^{(i)}$  are near zero and  $\hat{\lambda}_T^{(i)} < C_T^{(i)}$  for all  $i$ . This also confirms Romer and Romer (2000) with  $\hat{\lambda}_T^{(i)}$  small near zero.
3. Greenbook's dominance over the SPF-percentiles is more significant in inflation forecast than in real output growth forecast. For real output growth, there are many SPF percentiles that are not encompassed by Greenbook. The best SPF percentiles are found near the SPF-median for real output growth. For inflation forecasts, all SPF percentiles are encompassed by Greenbook.

For the sub-period **After-2000** in Figure 4, we note that the sample size is small as it is only for 6 years for 2001Q1 – 2006Q4. Nevertheless the encompassing results are clear.

1. For the real output growth forecast for  $h = 1$ , lower and middle SPF percentiles are encompassed by Greenbook with  $\hat{\lambda}_T^{(i)} < C_T^{(i)}$  while many upper SPF percentiles are not encompassed by Greenbook with  $\hat{\lambda}_T^{(i)} > C_T^{(i)}$ . The best SPF percentile with the largest value of  $\hat{\lambda}_T^{(i)}$  is above the median as seen from Figure 4(a,b). There are many large positive values of  $\hat{\lambda}_T^{(i)}$  (significantly larger than zero) over a wide range of SPF percentiles for  $h = 4$ .
2. For the inflation forecast many lower SPF percentiles are not encompassed by Greenbook as seen from Figure 4(c,d). For  $h = 1$ ,  $\hat{\lambda}_T^{(i)}$  are above zero for almost all percentiles  $i$ , and even significantly larger than zero ( $\hat{\lambda}_T^{(i)} > C_T^{(i)}$ ) for many lower percentiles  $i$  in the left tail. For

$h = 4$ , many SPF percentiles in the left tail are not encompassed by Greenbook and the best SPF percentile is found near the 13th percentile. This may show that the findings of Romer and Romer (2000) have got weakened in this recent period.

3. Greenbook's dominance over the SPF-percentiles has become weaker. There are many SPF percentiles that are not encompassed by Greenbook for both real output growth and inflation for both  $h = 1, 4$ . The best SPF percentiles are found above the SPF-median for real output growth ( $h = 1, 4$ ) but they are far below the SPF-median for inflation ( $h = 1, 4$ ).

To summarize, Greenbook's dominance over the SPF-percentiles is more significant in inflation forecast than in real output growth forecast. It implies that Greenbook forecasters' information advantage over the SPF participants is more significant in forecasting inflation than in forecasting real output growth. Also, Greenbook's dominance over the SPF-percentiles is more significant in the full data period as Greenbook encompasses the SPF percentiles in full data period. However, evidence in sub-periods indicates that these have changed over time as noted by Rossi and Sekhposyan (2016), and many SPF percentiles are not encompassed by Greenbook in more recent period. The encompassing results for the three sub-periods in Figures 2, 3, 4 are more significant than for the full data period in Figure 1. While most SPF percentiles are encompassed by Greenbook, there are many SPF percentiles not encompassed by Greenbook, in forecasting real output growth in all three sub-periods and in forecasting inflation in Before-1982 and especially After-2000. Among all SPF percentiles that are not encompassed by Greenbook, the best SPF percentile is near or above the median of the SPF cross-sectional distribution for real output growth forecast. But it is in the lower percentiles for inflation forecast for the sub-period Before-1982 (Figure 2d) and the sub-period After-2000 (Figure 4(c,d)). In all three sub-periods Greenbook's encompassing of the SPF-percentiles is much more significant in inflation forecast than in real output growth forecast. While the weights of all SPF percentiles in forecasting inflation are around zero in the full date period, some lower percentiles in the sub-period After-2000 (Figure 4(c,d)) are not encompassed by Greenbook in forecasting inflation. This indicates that inflation forecasts of lower SPF percentiles provide useful information in addition to the Greenbook after 2000.

## 4 Conclusions

Greenbook forecasts are used by the policy makers but they are not made available publicly until five years later. We ask a question how SPF may be used as an alternative forecast until the Greenbook forecast becomes available public. This question prompted us to consider the cross-sectional percentiles of the SPF survey. Because there are frequent replacements in the membership of the SPF forecasters due to entries and exits, the SPF does not produce balanced panel data of forecasts. Therefore, instead of following a panel of the individual forecasters, we examine the cross-sectional SPF-percentiles and look for which parts of the SPF cross-sectional distribution can be good (or bad) substitutes for Greenbook forecast, so that the users of the SPF can have the forecasts that are closest to the Greenbook forecasts of the policy makers in the FRB. For that matter, we test which SPF-percentiles are not encompassed by the Greenbook forecast. The encompassing test is conducted under the estimated Greenbook's loss function. For doing it we have introduced the new forecast encompassing test for the asymmetric least squares regression.

According to our encompassing test results, the common practice of using the SPF-median could be misleading, especially in forecasting inflation. The best SPF percentiles for inflation forecast that are not encompassed by Greenbook are far to the left away from the median in the low tail percentiles of the SPF cross-sectional distribution. Hence, if the SPF-median were to be used, it would over-predict inflation relative to Greenbook.

## 5 Appendix

The appendix explains how we compute  $\hat{\lambda}_T^{(i)}$  and  $\text{se}(\hat{\lambda}_T^{(i)})$ . Consider the linear expectile regression

$$y_t = x_t' \beta(\alpha) + u_t(\alpha), \quad (15)$$

where  $y_t$  is a scalar dependent variable and  $x_t$  is a  $k \times 1$  vector. The  $k \times 1$  parameter  $\beta(\alpha)$ , the asymmetric least squares (ALS) estimator, minimizes the loss function in (14) with  $p = 2$

$$E |\alpha - 1(u_t(\alpha) < 0)| \cdot u_t^2(\alpha) := E w_t(\alpha) \cdot u_t^2(\alpha), \quad (16)$$

with  $w_t(\alpha) = |\alpha - 1(u_t(\alpha) < 0)|$ , by solving the following equation iteratively

$$\hat{\beta}_T(\alpha) = \left\{ \sum_{t=1}^T |\alpha - 1(y_t < x_t' \hat{\beta}_T(\alpha))| \cdot x_t x_t' \right\}^{-1} \sum_{t=1}^T |\alpha - 1(y_t < x_t' \hat{\beta}_T(\alpha))| \cdot x_t y_t. \quad (17)$$

Newey and Powell (1987, pp. 827-828) show the asymptotic normality of  $\hat{\beta}_T(\alpha)$  and its consistent covariance matrix estimator. That is, for the simple case when  $k = 1$  as in our model in (12),

$$\sqrt{T} \hat{D}_T^{-1/2}(\alpha) \left( \hat{\beta}_T(\alpha) - \beta(\alpha) \right) \xrightarrow{d} N(0, 1) \quad (18)$$

where  $\hat{D}_T(\alpha) = \hat{W}_T^{-2}(\alpha) \hat{V}_T(\alpha)$ ,  $\hat{W}_T(\alpha) = \frac{1}{T} \sum_{t=1}^T \hat{w}_t(\alpha) x_t^2$ ,  $\hat{V}_T(\alpha) = \frac{1}{T} \sum_{t=1}^T \hat{w}_t^2(\alpha) \hat{u}_t^2(\alpha) x_t^2$ ,  $\hat{u}_t(\alpha) = y_t - x_t' \hat{\beta}_T(\alpha)$ , and  $\hat{w}_t(\alpha) = |\alpha - 1(\hat{u}_t(\alpha) < 0)|$ .

In our notation,  $\alpha = \alpha(\mathbf{f}^{GB})$ ,  $\beta(\alpha) = \lambda^{(i)}$ ,  $k = 1$ ,  $y_t = e_t^{GB}$ , and  $x_t = (e_t^{GB} - e_t^{SPF(i)})$ . The ALS estimator  $\hat{\lambda}_T^{(i)}$  is computed iteratively from

$$\begin{aligned} \hat{\lambda}_T^{(i)} &= \left[ \sum_{t=1}^T \left| \hat{\alpha}_T(\mathbf{f}^{GB}) - 1 \left\{ e_t^{GB} < \hat{\lambda}_T^{(i)} (e_t^{GB} - e_t^{SPF(i)}) \right\} \right| \cdot (e_t^{GB} - e_t^{SPF(i)})^2 \right]^{-1} \\ &\quad \times \left[ \sum_{t=1}^T \left| \hat{\alpha}_T(\mathbf{f}^{GB}) - 1 \left\{ e_t^{GB} < \hat{\lambda}_T^{(i)} (e_t^{GB} - e_t^{SPF(i)}) \right\} \right| \cdot (e_t^{GB} - e_t^{SPF(i)}) e_t^{GB} \right]. \end{aligned} \quad (19)$$

The asymptotic standard error of  $\hat{\lambda}_T^{(i)}$  is  $\text{SE}(\hat{\lambda}_T^{(i)}) = T^{-1/2} \hat{D}_T^{1/2}(\alpha)$ . The asymptotic standard errors that we compute here do not incorporate the effect of the estimation uncertainty in  $\hat{\alpha}_T$  in constructing the standard error of  $\hat{\lambda}_T^{(i)}$  and thus it may understate the standard error.



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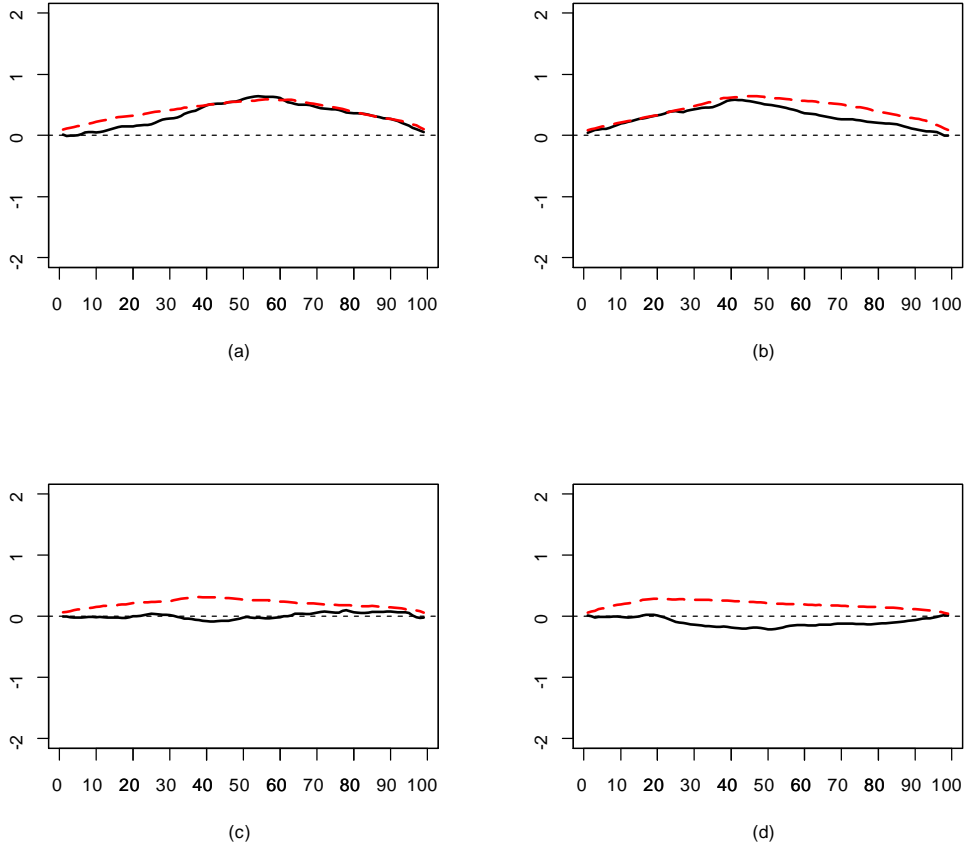
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**Table 1. Estimation of the Greenbook Loss Function and Diagnostics**

	$y_{t+h}$	$\hat{\alpha}_T(\mathbf{f}^{GB})$	$J_T(\mathbf{f}^{GB}; \hat{\alpha}_T(\mathbf{f}^{GB}))$	$J_T(\mathbf{f}^{GB}; 0.5)$
Full data period	real output growth, $h = 1$	.586 [.064]	0.527 (.468)	2.370 (.306)
	real output growth, $h = 4$	.579 [.074]	0.006 (.940)	1.163 (.559)
	inflation, $h = 1$	.529 [.077]	0.006 (.938)	0.143 (.931)
	inflation, $h = 4$	.603 [.093]	0.004 (.949)	1.226 (.542)
Before-1982	real output growth, $h = 1$	.732 [.085]	1.452 (.228)	8.848 (.012)
	real output growth, $h = 4$	.861 [.103]	4.228 (.004)	16.546 (.000)
	inflation, $h = 1$	.407 [.123]	1.267 (.260)	1.841 (.398)
	inflation, $h = 4$	.156 [.109]	1.648 (.199)	11.672 (.003)
1982-2000	real output growth, $h = 1$	.351 [.090]	1.208 (.272)	3.974 (.137)
	real output growth, $h = 4$	.371 [.100]	0.867 (.352)	2.544 (.280)
	inflation, $h = 1$	.780 [.057]	0.209 (.648)	24.622 (.000)
	inflation, $h = 4$	.884 [.047]	0.864 (.353)	66.381 (.000)
After-2000	real output growth, $h = 1$	.856 [.066]	1.771 (.192)	30.624 (.000)
	real output growth, $h = 4$	.778 [.078]	0.255 (.614)	13.160 (.001)
	inflation, $h = 1$	.139 [.121]	0.607 (.436)	9.472 (.009)
	inflation, $h = 4$	.111 [.066]	1.395 (.238)	36.409 (.000)

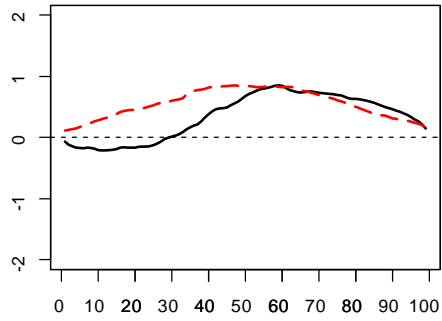
Notes: Column 3 reports the estimates  $\hat{\alpha}_T(\mathbf{f}^{GB})$  and their asymptotic standard errors [in square brackets] for Greenbook forecast  $\mathbf{f}^{GB}$ . Column 4 reports the over-identifying test statistics that check for adequacy of the estimated  $\alpha$  values with the asymptotic  $p$ -values of the test statistics (in parentheses). Column 5 reports the test statistics for adequacy of the symmetric loss with  $\alpha = 0.5$  values with the asymptotic  $p$ -values of the test statistics (in parentheses). The full data period and three sets of sub-period data are used as indicated in Column 1.

**Figure 1. Forecast Encompassing Test: Full Data Period**

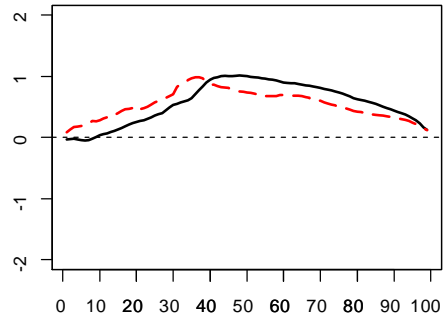


Notes: The solid black line is the estimates of  $\hat{\lambda}_T^{(i)}(\hat{\alpha}_T(\mathbf{f}^{GB}))$  for different  $SPF(i)$ . The abscissa represents the  $i$ th SPF-percentile. The dashed red line is the 5% asymptotic critical values  $1.645 \times \text{se}(\hat{\lambda}_T^{(i)}(\hat{\alpha}_T(\mathbf{f}^{GB})))$ , and the dotted line is for  $H_0 : \lambda^{(i)} = 0$ . Panel (a) is for real output growth forecast with  $h = 1$ , Panel (b) is for real output growth forecast with  $h = 4$ , Panel (c) is for inflation forecast with  $h = 1$ , and Panel (d) is for inflation forecast with  $h = 4$ .

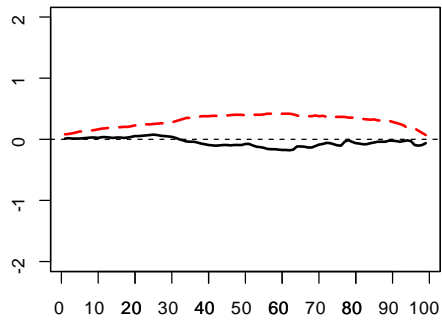
Figure 2. Forecast Encompassing Test: Before-1982



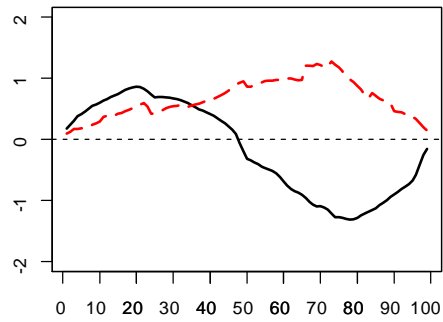
(a)



(b)



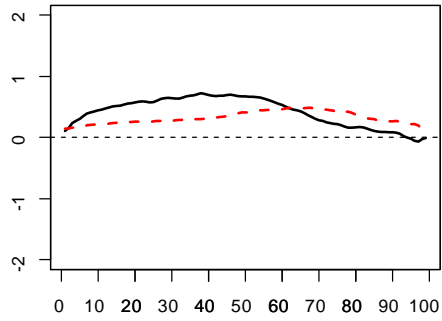
(c)



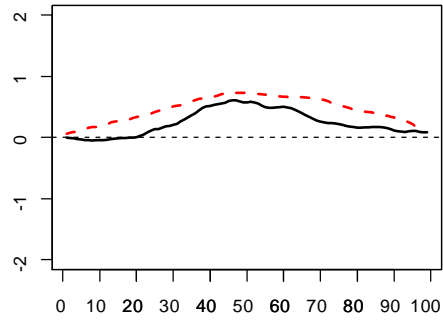
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Notes: See Figure 1.

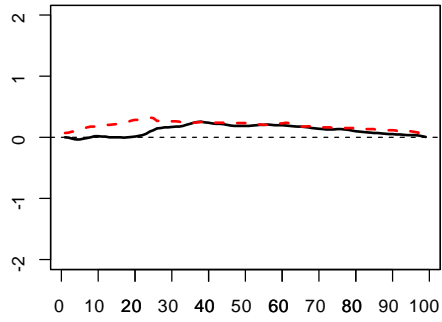
Figure 3. Forecast Encompassing Test: 1982-2000



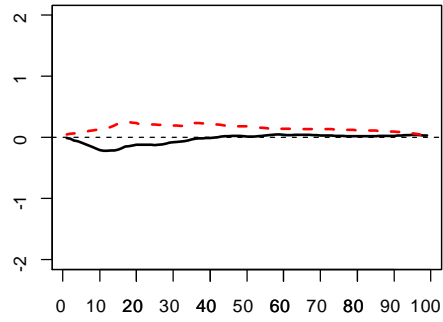
(a)



(b)



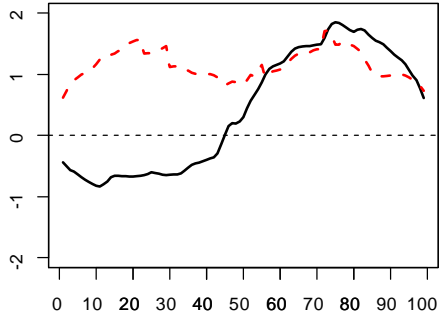
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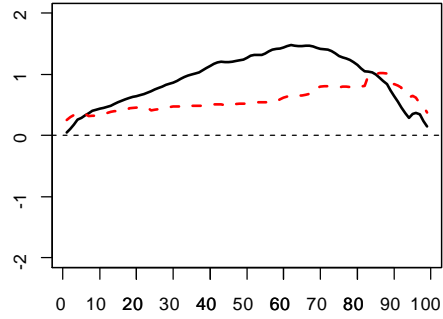
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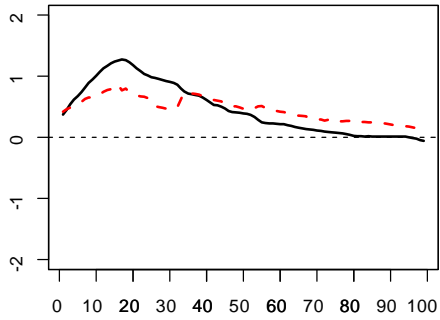
Figure 4. Forecast Encompassing Test: After-2000



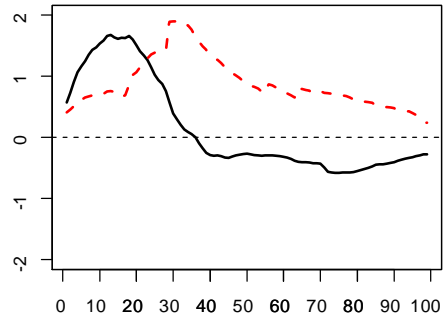
(a)



(b)



(c)



(d)

Notes: See Figure 1.