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Forecasting using targeted diffusion indexes

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Abstract

The simplicity of the standard diffusion index model of Stock and Watson has certainly contributed to its success among practitioners resulting in a growing body of literature on factor-augmented forecasts. However, as pointed out by Bai and Ng, the ranked factors considered in the forecasting equation depend neither on the variable to be forecasted nor on the forecasting horizon. We propose a refinement of the standard approach that retains the computational simplicity while coping with this limitation. Our approach consists of generating a weighted average of all the principal components, the weights depending both on the eigenvalues of the sample correlation matrix and on the covariance between the estimated factor and the targeted variable at the relevant horizon. This "targeted diffusion index" approach is applied to US data and the results show that it outperforms considerably the standard approach in forecasting several major macroeconomic series. Moreover, the improvement is more significant in the final part of the forecasting evaluation period.

Keywords: Diffusion index, forecasting, factor models, US, targeted predictors.

JEL classification: C22, C53

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1 Introduction

Recently, there has been an increasing focus on factor models for forecasting purposes. In a context of growing data availability, the popularity of such models relies on the fact that they allow to exploit the information contained in large datasets in a simple and parsimonious way. A considerable amount of work has been conducted along this line of research, including the seminal work of Stock and Watson (1999, 2002a, 2002b) for the US, Marcellino *et al.* (2003) for the euro area, Artis *et al.* (2005) for the UK, among others. The basic idea underlying the estimation of the diffusion index model is that one can summarize in the first few principal components a significant fraction of the overall covariation among the series in the panel. In practice, the principal components obtained from the original dataset are ranked according to the proportion of the total variance explained by each one. The number of factors to be considered in the forecasting equation is usually either fixed or can be chosen based on some criteria (see, for example, Stock and Watson (1998) and more recently Bai and Ng (2002)). Those factors are used as regressors in forecasting equations providing what is known as factor-augmented forecasts.

However, such a modelling strategy suffers from an important shortcoming. The static factors used in the forecasting process do not take into account the specific variable being forecasted, as pointed out by Bai and Ng (2007a, 2007b). The factors extracted from the dataset are ordered according to their ability to express the common movement in the whole dataset, irrespective of the targeted variable or the forecasting horizon. By including only the first few factors in the forecasting equation, the information provided by all the other factors is completely discarded, neglecting any possible correlation that they might present with the target variable at the relevant forecasting horizon.

To overcome such caveat, Bai and Ng (2007a) proposed a methodology which involves partitioning the panel of predictors in two subsets, one that includes all the variables containing relevant information for the specific variable to be forecasted and the other subset that includes the non-informative variables. For this identification purpose a thresholding rule is used to disentangle the relevant and irrelevant regressors for the specific variable. They called the relevant regressors "targeted predictors". From the subset of targeted predictors, static factors are extracted using the principal components method and thereafter estimation of the forecasting equation proceeds as in the standard diffusion index model case. In an alternative approach, Bai and Ng (2007b) do not exclude any variable from the initial panel from which the set of static factors are extracted. Following the estimation of the static factors, instead of relying only on the top ranked principal components for the forecasting equation, they re-rank the whole set of factors taking into consideration their correlation with the variable to be forecasted. Thereafter only a finite set of these top ranked correlated factors are retained in the forecasting equation. They rely on boosting as a method for the selection of the most informative factors to avoid the in-sample overfitting problem.

In this paper, we take a different approach which aims at reconciling the original spirit of Stock and Watson and the targeting principle raised by Bai and Ng, while keeping the computational procedure simple. We acknowledge that the variables to be included in the forecasting models should depend on the variable to be forecasted and the ranking of factors à la Stock and Watson should not be ignored. Instead of picking a small number of factors associated with the largest eigenvalues of the sample correlation matrix, we propose to include in the forecasting model a synthetic regressor defined as a linear combination of all the estimated factors. This synthetic indicator, which we will refer to as "targeted diffusion index" (TDI), has a weight attached to each factor which reflects both the fraction of the overall covariation of the series represented by that factor and its ability to forecast the variable of interest at the relevant horizon.

The approach herein presented is put to test to forecast several major US macroeconomic variables using the dataset taken from Stock and Watson (2005). The results obtained are quite encouraging. The targeted diffusion index outperforms, in general, the standard diffusion index model approach of Stock and Watson for the whole evaluation period as well as for different sub-periods, in particular from 1990 onwards. The latter is worth stressing because it is well known that the standard diffusion index approach and its extensions have shown some difficulty to improve on the forecasting performance of a simple univariate autoregressive model in the final part of the evaluation period considered.

The paper is organized as follows. In section 2, the econometric motivation of the TDI is set forward. The empirical results are discussed in section 3. Finally, section 4 concludes.

2 The targeted diffusion index

Suppose we have data on a large number of predictors, N, observed at T time periods: $X = [X_1 \cdots X_t \cdots X_T]'$, where $X_t = [X_{t,1} \cdots X_{t,n} \cdots X_{t,N}]'$. We are interested in forecasting y_{T+h}, the value of the variable y for period $T + h$ (this targeted variable may or may not be included in X). We will consider that both the predictors and the targeted variable are stationary (or have been previously stationarized) and that the data generating process for X_t admits a static factor representation:

$$X_t = \Lambda F_t + e_t \quad (t = 1, \cdots, T) \tag{1}$$

where F_t is a $(r \times 1)$ vector of non-observable (static) factors, Λ is a $(N \times r)$ matrix of (unknown) loadings and e_t is a N-dimensional vector of the idiosyncratic components. Under slightly different sets of assumptions on the loadings and on the generating processes of F_t and e_t, Stock and Watson (1998, 2002b), Bai and Ng (2002) and Amengual and Watson (2007) have shown that the first k principal components $\hat{F}^{(k)} = \left[\hat{F}_1 \cdots \hat{F}_k\right]$ $(T \times k)$ obtained from $(NT)^{-1}X'X$ (or, equivalently, from $(NT)^{-1}XX'$) span a subspace of dimension $\min(k, r)$ of the true factor space when both $N \to \infty$ and $T \to \infty$ (if $k \geq r$ the whole factor space is asymptotically spanned)[1].

The standard multi-step diffusion index approach to forecast y_{T+h} is based on the least squares estimation of equation:

$$y_{t+h} = \alpha_0 + \sum_{i=1}^{k} \alpha_i \hat{F}_{t,i} + \sum_{j=1}^{p} \gamma_j y_{t+1-j} + \varepsilon_{t+h} \quad (t = p, \cdots, T-h) \tag{2}$$

In their empirical application, Stock and Watson (2002a) coined the version of (2) without the autoregressive terms (i.e. with $\gamma_j = 0$ for $j = 1, \cdots, p$) as the diffusion index equation (DI) and the complete version with lags of the targeted variable as the diffusion index - autoregressive equation (DI-AR). The number of estimated factors k to be included in the forecasting equation may be determined by minimizing either a modified version of the Bayesian information criteria (BIC) suggested by Stock and Watson (1998) or the criteria proposed by Bai and Ng (2002) (in the latter case, previously to the estimation of equation (2)). As regards the number p of autoregressive terms, it is usually determined by the standard BIC criterion.

Let $X_{(h)} = [X_1 \cdots X_t \cdots X_{T-h}]'$ $((T-h) \times N)$ and $y_{(h)} = [y_{1+h} \cdots y_{t+h} \cdots y_T]'$ $((T-h) \times 1)$. We will denote by $\mu_{(h)1} \geq \cdots \geq \mu_{(h)n} \geq \cdots \geq \mu_{(h)N}$ the eigenvalues of $[N(T-h)]^{-1} X'_{(h)} X_{(h)}$, by $\hat{\Lambda}_{(h)}$ the corresponding $(N \times N)$ matrix of eigenvectors such that

$$\frac{1}{N^2(T-h)} \hat{\Lambda}'_{(h)} X'_{(h)} X_{(h)} \hat{\Lambda}_{(h)} = I$$

and by

$$\hat{F}_{(h)} = \left[\hat{F}_{(h)t,n}\right]_{t=1,\cdots,T;n=1,\cdots N} = \frac{1}{N} X \hat{\Lambda}_{(h)} \tag{3}$$

the "extended" $(T \times N)$ matrix of principal components. Instead of equation (2), we propose to estimate by least squares the following equation:

$$y_{t+h} = \beta_0 + \beta_1 \hat{F}^*_{(h)t} + \sum_{j=1}^{p} \rho_j y_{t+1-j} + u_{t+h} \tag{4}$$

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[1] The typical assumptions allow for some heteroskedasticity and limited dependence of the idiosyncratic components in both the time and cross-section dimensions, as well as for moderate correlation between the latter and the factors.

where $\hat{F}^*_{(h)t}$ is the targeted diffusion index for horizon h defined as:

$$\hat{F}^*_{(h)t} = \sum_{n=1}^{N} \varpi_{(h)n} \hat{F}_{(h)t,n} \quad (t = 1, \cdots, T) \tag{5}$$

a linear combination of the estimated factors, with

$$\varpi_{(h)n} = \frac{\omega_{(h)n}}{\sum_{i=1}^{N} \omega_{(h)i}} \quad (n = 1, \cdots, N) \tag{6}$$

and

$$\omega_{(h)n} = \left(\frac{1}{T-h} \sum_{t=1}^{T-h} \hat{F}'_{(h)t,n} y_{t+h} \right) \left(\frac{\mu_{(h)n}}{\mu_{(h)1}} \right) \quad (n = 1, \cdots, N) \tag{7}$$

In analogy with the notation used by Stock and Watson, we will refer to the forecasts generated with equation (4) as the TDI or the TDI-AR forecasts, respectively when the autoregressive terms are dropped from the equation or when they are included.

Before normalization, the weight attached to the n-th principal component is simply the product of, on the one hand, the sample covariance between that principal component and the variable to be forecasted h periods ahead and, on the other hand, the ratio of n-th to the largest eigenvalue of $[N(T-h)]^{-1} X'_{(h)} X_{(h)}$. The larger $\mu_{(h)n}$ is relative to the remaining eigenvalues, the more the estimated factor $\hat{F}_{(h)n}$ is aligned with the directions of the common movement of the dataset $X_{(h)}$. Therefore, setting the weight of each principal component proportional to the corresponding eigenvalue relies on the same intuition as the one underlying the standard diffusion index approach, but without the truncation of the weights for $n > k$. In addition, by letting the weight to depend on the sample covariance between the factor and the variable to be forecasted, at the relevant horizon, the targeted diffusion index explicitly takes into account the specificity of the latter variable. For $n = 1$, $\omega_{(h)1}$ is simply the sample covariance between the estimated factor and the variable to be forecasted h periods ahead. However, for $n > 1$ and since $\mu_{(h)n} < \mu_{(h)1}$, the sample covariance between $\hat{F}_{(h)t,n}$ and y_{t+h} is shrunk by the ratio $\mu_{(h)n}/\mu_{(h)1}$, therefore avoiding the overfitting problem that typically plagues forecasts based on too many predictors.

Note that $\omega = [\omega_1 \cdots \omega_n \cdots \omega_N]'$ is proportional to the optimal solution of the problem of penalized least squares (with orthogonal regressors):

$$\min_{c} \left\{ \left[\sum_{t=1}^{T-h} \left(y_{t+h} - c_0 - \hat{F}'_{(h)t} c \right)^2 \right] + \left[\sum_{n=1}^{N} \left(\frac{\mu_{(h)1}}{\mu_{(h)n}} - 1 \right) c_n^2 \right] \right\} \tag{8}$$

where $c = [c_1 \cdots c_n \cdots c_N]'$ is a vector of coefficients and

$$\hat{F}_{(h)t} = \left[\hat{F}_{(h)t,1} \cdots \hat{F}_{(h)t,n} \cdots \hat{F}_{(h)t,N} \right]'$$

The size of the penalty imposed on the coefficient of each principal component varies inversely with the eigenvalue $\mu_{(h)n}$. In the limiting case $\mu_{(h)n} = 0$ the penalty is infinite, contrasting with the other limiting case $\mu_{(h)n} = \mu_{(h)1}$, for which the penalty is null.

As usually with penalized least squares problems, the penalty function in (8) can be regarded as proportional to a Bayesian prior distribution for the coefficients in the linear regression of y_{t+h} on the N principal components:

$$y_{t+h} = c_0 + \hat{F}'_{(h)t}c + v_{t+h} \tag{9}$$

To minimize (8) is equivalent to maximize the log posterior distribution of

$$(c_0, c) \mid \left(y_{(h)}, X_{(h)}\right) \tilde{}A \exp\left\{-\frac{1}{2}\left[\sum_{t=1}^{T-h}\left(y_{t+h} - c_0 - \hat{F}'_{(h)t}c\right)^2 + \sum_{n=1}^{N}\left(\frac{\mu_{(h)1}}{\mu_{(h)n}} - 1\right)c_n^2\right]\right\} \tag{10}$$

where A is a positive constant. Thus, the penalty in (8) can be interpreted as proportional to the logarithm of a normal distribution taken as the prior for the coefficients in regression (9). Because the penalty is a summation, it implies that *a priori* the coefficients are admitted to be mutually independent, although not identically distributed. The prior of c_0 is diffuse, while the priors of the remaining coefficients all have zero means but their variances

$$\frac{\mu_{(h)n}}{\mu_{(h)1} - \mu_{(h)n}}$$

depend on the fraction of the overall variation of the dataset represented by the associated principal component. When $\mu_{(h)n}$is close to zero, the coefficient is practically restricted to be zero, while when $\mu_{(h)n}$ approaches $\mu_{(h)1}$ the prior becomes diffuse.

Typically, penalized least squares problems include a tuning parameter that allows to attach different relative weights to the penalty term. In this spirit, we could have considered, instead of (8):

$$\min_{c}\left\{\left[\sum_{t=1}^{T-h}\left(y_{t+h} - c_0 - \hat{F}'_{(h)t}c\right)^2\right] + \theta\left[\sum_{n=1}^{N}\left(\frac{\mu_{(h)1}}{\mu_{(h)n}} - 1\right)c_n^2\right]\right\} \tag{11}$$

where θ is a positive tuning parameter. The solution of this generalized version is proportional to (for $n = 1, \cdots, N$):

$$\omega_{(h)n}(\theta) = \left(\frac{1}{T-h}\sum_{t=1}^{T-h}\hat{F}'_{(h)t,n}y_{t+h}\right)\left(\frac{\mu_{(h)n}}{\theta\mu_{(h)1} + (1-\theta)\mu_{(h)n}}\right) \tag{12}$$

We will denote by TDI(θ) and TDI(θ)-AR the forecasts generated by this generalized version of the targeted diffusion index with tuning parameter θ, when not including and when including the lagged variable in the forecasting equation, respectively. The difficulty associated with these generalized versions is the choice of θ. As discussed in the next section, the performance of the targeted diffusion index approach does not seem to be very sensitive to the choice of the tuning parameter. Hence, choosing $\theta = 1$ is in general quite satisfactory in terms of the forecasting performance.

3 Empirical results

In this section, we evaluate the relative performance of the suggested approach resorting to the US monthly dataset of Stock and Watson (2005), which covers the period from January 1959 up to December 2003, encompassing 132 macroeconomic time series. Following Stock and Watson (2005), the series are transformed by taking logs, first or second differences when necessary to assure approximate stationarity after transformation and we use both outlier-adjusted and outlier-unadjusted versions of the series[2]. The outlier-adjusted series are used for the estimation of the factors whereas all the remaining analysis is performed with outlier-unadjusted series.

The focus is on forecasting ten major monthly US macroeconomic variables: personal income less transfer payments (a0m051)[3], retail sales (a0m059), real consumption (a0m224_r), total industrial production (ips10), private employment (ces002), hours worked in nonagricultural establishments (a0m048), consumer price index (punew), consumer price index excluding food (puxf), Federal funds interest rate (fyff) and 10-year Treasury bonds yield (fygt10). This set of series comprises the most important real and nominal monthly variables for which forecasts have been conducted elsewhere in the related strand of literature.

For each series, several forecasting alternatives are assessed. Following Stock and Watson (2002a), we consider an autoregressive forecast as the benchmark and use the Bayesian Information Criterion (BIC) for lag order selection. However, since some authors (see, for instance, Bai and Ng (2007a, 2007b) and Boivin and Ng (2006)) have considered AR(4) forecasts as the benchmark model, we also have dealt with this case in the empirical application.

We also consider the two variants of the standard diffusion index model, DI and DI-AR, and the corresponding versions of the targeted diffusion index approach, TDI and TDI-AR.

As in Stock and Watson (2002a), we mimic a real-time forecasting exercise with recursive factor estimation, parameter estimation, model selection, and so forth. Moreover, as it has

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[2] As in Stock and Watson (2005), the outlier adjustment corresponds to replacing observations of the transfomed series with absolute deviations larger than six times the interquartile range by the median value of the preceding five observations.

[3] These codes correspond to the mnemonics used in Stock and Watson (2005) and in other papers.

been standard practice in this strand of literature applied to the US, the forecast evaluation period starts in January 1970. We compute the mean squared error (MSE) for each of the competing models relative to the autoregressive benchmark. Regarding the forecasting horizon, we focus on the 12-month horizon ($h = 12$) as it has received more attention in the literature (see, for example, Boivin and Ng (2006) and Bai and Ng (2007a)). Nevertheless, we also performed the same exercise for other common forecast horizons, namely $h = 6, 9, 18, 24$, to assess the robustness of the findings, and qualitatively similar results have been obtained[4].

The out-of-sample forecast evaluation period runs from January 1970 up to December 2003. Following Bai and Ng (2007b), we present the results for the forecast evaluation period as a whole as well as for several decades: 70's, 80's and 90's. Additionally, we also present results for the period from the beginning of the 90's up to the end of the sample. Such detailed information on the forecasting performance over the sample is relevant as it has been much harder to beat the simple univariate autoregressive model in the latter forecasting period (see, for example, Stock and Watson (2007)).

Regarding the results obtained from the benchmark model (Table 1), one can see that setting the autoregressive lag order to 4 turns out to be typically worse than selecting the number of lags relying on the BIC criteria. In particular, the deterioration is more pronounced for the price series, specially in the most recent subsample period where the results deteriorate considerably. Hence, we will consider the AR(p) model with BIC chosen p as the benchmark.

In Table 2, we present the empirical results for the DI and the TDI cases. One can see that for all series with the exception of retail sales, the TDI forecasts outperform the DI forecasts when one considers the forecast evaluation period as a whole. The average reduction of the relative MSE (excluding retail sales) exceeds 13 percentage points (p.p.). When analyzing the results by subsample periods, the TDI outperforms the DI in 37 out of the total of 40 cases considered. The average reduction, excluding retail sales, of the relative MSE in the 70's is around 13 p.p., in the 80's about 10 p.p., in the 90's almost 30 p.p. and from the beginning of 90's up to the end of 2003, the reduction is near 34 p.p. Hence, the TDI forecasts clearly dominate the DI forecasts over the whole sample and the gains are particularly striking in the latter part of the sample. Moreover, the TDI forecasts compare more favorably with the benchmark model than the DI forecasts. Excluding the consumer prices series, there are only two series and at for the latter part of the sample where the AR(p) dominates the TDI forecasts. Recall that both the TDI and the DI versions do not include lags of the dependent variable.

Allowing for the autoregressive lags, i.e. considering TDI-AR and DI-AR versions, in

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[4] These results are available from the authors upon request.

general the results do not improve in comparison with the TDI and DI versions, in terms of relative MSE (Table 3). The main exception concerns the consumer price series. In fact, Stock and Watson (2002a) also found that, for the price series, augmenting the regression with lags of the dependent variable significantly improved the forecasting performance whereas for the other variables it did not. For the two consumer prices series considered, overall and excluding food items, the TDI-AR and DI-AR outperform the univariate autoregressive model in all the forecast periods, with the TDI-AR forecasts showing a better performance than the DI-AR forecasts in the final part of the evaluation period.

The above analysis has been conducted by setting the tuning parameter θ to 1. In table 4, we present the forecasting performance of the targeted diffusion index models when θ is chosen so as to minimize the MSE for the forecast evaluation period as a whole. One can see that the differences are negligible in the relevant cases and therefore imposing $\theta = 1$ provides quite robust results in terms of the forecasting performance across series.

4 Conclusions

Forecasting macroeconomic series with diffusion index models, as proposed by Stock and Watson (1998, 2002a, 2002b), opened up a new line of research followed by several empirical applications. This framework allows to explore very large datasets for forecasting by first summarizing the relevant information contained in the whole set of series into a small number of principal components which are thereafter used in the forecasting equation. In this way, it is possible to somehow circumvent the usual degrees of freedom problem. The forecast performance of the factor based models has proved to be superior to a handful of alternative benchmark models. However, there is still room for improvement in terms of forecast performance within this framework. In particular, as pointed out by Bai and Ng (2007a, 2007b), in the standard approach the ranking of the factors to be included in the forecasting equation depends neither on the variable to be forecasted nor on the forecasting horizon.

This paper proposes a modelling strategy that retains the original spirit of the standard diffusion index model of Stock and Watson while taking into account the targeted predictor issue raised by Bai and Ng. In practice a linear combination of the whole set of factors is computed, where the coefficients depend on the variable to be forecasted as well as on the forecasting horizon. Such linear combination based on the entire set of factors can be seen as a specific synthetic predictor for the h-period ahead targeted variable. Moreover, the suggested targeted diffusion index model retains the computational simplicity found in the standard diffusion index model.

The relative performance of the suggested approach was empirically assessed resorting to the US monthly dataset of Stock and Watson (2005) and the forecast evaluation was performed for ten major monthly US macroeconomic variables. Overall, the targeted diffusion index approach provides out-of-sample forecasts for the 12-month horizon that clearly outperform the standard diffusion index forecasts. For the January 1970 to December 2003 forecasting evaluation period, the average reduction of the relative MSE, with the exception of retail sales, exceeds 13 p.p. In terms of subsamples, the average reduction in the 70's is around 13 p.p., in the 80's about 10 p.p., in the 90's almost 30 p.p. and from the beginning of 90's up to the end of 2003, the reduction is near 34 p.p. Hence, the suggested TDI forecasts outperforms the standard DI forecasts over the whole out-of-sample period and the improvement is quite substantial in the final part of the evaluation period.

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Table 1 - MSE of AR(4) (relative to AR(*p*) with *p* chosen by BIC) for a 12-month horizon

code	**series**	**70:01-03:12**	**70:01-79:12**	**80:01-89:12**	**90:01-99:12**	**90:01-03:12**
a0m051	personal income	0.956	0.940	1.008	0.933	0.944
a0m059	retail sales	1.006	1.021	0.998	0.995	0.991
a0m224	private consumption (real)	1.012	1.080	0.969	0.926	0.946
ips10	industrial production	1.004	1.023	0.995	0.957	0.960
ces002	private employment	1.005	1.003	1.000	1.019	1.016
a0m048	hours worked (non-agricultural establishments)	0.966	0.980	0.928	0.982	0.991
punew	consumer prices index	1.009	0.928	1.013	1.235	1.245
puxf	consumer prices index excluding food	1.012	0.942	0.997	1.272	1.273
fyff	interest rate Fed Funds	1.057	1.020	1.082	1.065	1.052
fygt10	yield 10-year Treasury bonds	1.004	1.029	1.000	1.013	1.005

Note: Shaded area corresponds to a value higher than one.

Table 2 - MSE of DI and TDI (relative to AR(*p*) with *p* chosen by BIC) for a 12-month horizon

code		70:01-03:12	70:01-79:12	80:01-89:12	90:01-99:12	90:01-03:12
	DI					
a0m051	personal income	0.754	0.571	0.828	0.959	0.913
a0m059	retail sales	**0.725**	**0.620**	0.601	**1.058**	1.065
a0m224	private consumption (real)	0.802	0.734	**0.592**	1.253	1.312
ips10	industrial production	0.593	0.341	0.779	0.957	1.094
ces002	private employment	0.759	0.694	0.584	1.116	1.127
a0m048	hours worked (non-agricultural establishments)	0.635	0.526	0.519	0.899	0.988
punew	consumer prices index	1.746	1.506	1.544	2.894	3.148
puxf	consumer prices index excluding food	1.551	0.984	1.515	2.844	3.329
fyff	interest rate Fed Funds	0.743	0.667	0.838	0.528	0.566
fygt10	yield 10-year Treasury bonds	1.058	1.337	1.043	0.986	0.977
	TDI					
a0m051	personal income	**0.617**	**0.453**	**0.655**	**0.773**	**0.774**
a0m059	retail sales	0.740	0.683	**0.584**	1.062	**1.039**
a0m224	private consumption (real)	**0.759**	**0.718**	0.641	**1.042**	**1.053**
ips10	industrial production	**0.507**	**0.335**	**0.637**	**0.750**	**0.843**
ces002	private employment	**0.689**	**0.617**	**0.571**	**0.809**	**0.998**
a0m048	hours worked (non-agricultural establishments)	**0.590**	**0.506**	**0.513**	**0.729**	**0.846**
punew	consumer prices index	**1.384**	**1.151**	**1.303**	**2.313**	**2.369**
puxf	consumer prices index excluding food	**1.242**	**0.938**	**1.240**	**1.981**	**2.125**
fyff	interest rate Fed Funds	**0.693**	**0.561**	**0.827**	**0.436**	**0.505**
fygt10	yield 10-year Treasury bonds	**0.969**	**0.925**	**0.996**	**0.914**	**0.903**
	Differential (TDI vs. DI)					
a0m051	personal income	-0.138	-0.118	-0.173	-0.186	-0.139
a0m059	retail sales	0.015	0.063	-0.016	0.003	-0.025
a0m224	private consumption (real)	-0.043	-0.016	0.049	-0.211	-0.259
ips10	industrial production	-0.086	-0.007	-0.141	-0.207	-0.251
ces002	private employment	-0.070	-0.077	-0.013	-0.307	-0.129
a0m048	hours worked (non-agricultural establishments)	-0.045	-0.020	-0.006	-0.170	-0.143
punew	consumer prices index	-0.363	-0.355	-0.240	-0.581	-0.780
puxf	consumer prices index excluding food	-0.309	-0.046	-0.274	-0.863	-1.205
fyff	interest rate Fed Funds	-0.050	-0.106	-0.011	-0.092	-0.061
fygt10	yield 10-year Treasury bonds	-0.088	-0.412	-0.047	-0.072	-0.074

Note: Shaded area corresponds to a value higher than one and a bold format denotes the best model between DI and TDI.

Table 3 - MSE of DI-AR and TDI-AR (relative to AR(*p*) with *p* chosen by BIC) for a 12-month horizon

		70:01-03:12	70:01-79:12	80:01-89:12	90:01-99:12	90:01-03:12
code	**DI-AR**					
a0m051	personal income	0.778	0.603	0.870	0.965	0.916
a0m059	retail sales	0.761	0.714	0.577	**1.092**	**1.076**
a0m224	private consumption (real)	0.898	0.934	**0.569**	1.305	1.401
ips10	industrial production	0.642	0.381	0.887	0.835	1.071
ces002	private employment	0.850	0.860	0.606	1.083	**1.147**
a0m048	hours worked (non-agricultural establishments)	0.655	0.589	0.458	0.824	1.038
punew	consumer prices index	**0.654**	**0.679**	**0.566**	0.868	0.859
puxf	consumer prices index excluding food	0.840	0.889	0.789	0.869	0.899
fyff	interest rate Fed Funds	0.773	0.745	0.846	0.554	0.572
fygt10	yield 10-year Treasury bonds	1.083	1.567	1.048	0.986	0.977
	TDI-AR					
a0m051	personal income	**0.621**	**0.447**	**0.683**	**0.777**	**0.777**
a0m059	retail sales	**0.741**	**0.683**	**0.552**	1.128	1.082
a0m224	private consumption (real)	**0.763**	**0.714**	0.622	**1.112**	**1.112**
ips10	industrial production	**0.534**	**0.288**	**0.768**	**0.749**	**0.938**
ces002	private employment	**0.741**	**0.626**	**0.555**	**0.951**	1.232
a0m048	hours worked (non-agricultural establishments)	**0.561**	**0.455**	**0.408**	**0.701**	**0.957**
punew	consumer prices index	0.692	0.744	0.605	**0.803**	**0.808**
puxf	consumer prices index excluding food	**0.744**	**0.804**	**0.669**	**0.829**	**0.868**
fyff	interest rate Fed Funds	**0.701**	**0.566**	**0.833**	**0.459**	**0.523**
fygt10	yield 10-year Treasury bonds	**0.976**	**0.984**	**0.998**	**0.914**	**0.903**
	Differential (TDI-AR vs. DI-AR)					
a0m051	personal income	-0.157	-0.156	-0.187	-0.187	-0.139
a0m059	retail sales	-0.020	-0.031	-0.025	0.036	0.006
a0m224	private consumption (real)	-0.135	-0.221	0.053	-0.193	-0.289
ips10	industrial production	-0.107	-0.093	-0.119	-0.086	-0.133
ces002	private employment	-0.109	-0.234	-0.051	-0.132	0.085
a0m048	hours worked (non-agricultural establishments)	-0.094	-0.134	-0.050	-0.122	-0.082
punew	consumer prices index	0.038	0.064	0.039	-0.064	-0.051
puxf	consumer prices index excluding food	-0.096	-0.085	-0.120	-0.040	-0.030
fyff	interest rate Fed Funds	-0.073	-0.179	-0.013	-0.095	-0.049
fygt10	yield 10-year Treasury bonds	-0.107	-0.583	-0.050	-0.072	-0.074

Note: Shaded area corresponds to a value higher than one and a bold format denotes the best model between DI and TDI.

Table 4 - MSE of TDI and TDI-AR with θ optimal (relative to AR(*p*) with *p* chosen by BIC) for a 12-month horizon

		TDI (θ optimal)			TDI(θ optimal)-AR		
code	**series**	**θ optimal**	**70:01-03:12**	**Differential vs. TDI(1)**	**θ optimal**	**70:01-03:12**	**Differential vs. TDI(1)-AR**
a0m051	personal income	1.6	0.617	0.000	1.6	0.614	-0.007
a0m059	retail sales	1.0	0.740	0.000	1.2	0.741	0.000
a0m224	private consumption (real)	0.7	0.756	-0.004	0.7	0.762	-0.001
ips10	industrial production	0.5	0.498	-0.009	0.8	0.530	-0.004
ces002	private employment	0.5	0.675	-0.014	0.5	0.728	-0.014
a0m048	hours worked (non-agricultural establishments)	0.4	0.564	-0.026	0.4	0.550	-0.011
punew	consumer prices index	0.1	1.187	-0.196	4.8	0.670	-0.022
puxf	consumer prices index excluding food	0.1	1.242	0.000	1.5	0.743	-0.001
fyff	interest rate Fed Funds	1.1	0.693	0.000	1.3	0.699	-0.001
fygt10	yield 10-year Treasury bonds	0.3	0.964	-0.005	3.5	0.960	-0.016

Note: θ optimal denotes the value for θ that minimizes the MSE for the forecast evaluation period as a whole.

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