

Bermingham, Colin; D'Agostino, Antonello

**Working Paper**

## Understanding and forecasting aggregate and disaggregate price dynamics

ECB Working Paper, No. 1365

**Provided in Cooperation with:**

European Central Bank (ECB)

*Suggested Citation:* Bermingham, Colin; D'Agostino, Antonello (2011) : Understanding and forecasting aggregate and disaggregate price dynamics, ECB Working Paper, No. 1365, European Central Bank (ECB), Frankfurt a. M.

This Version is available at:

<https://hdl.handle.net/10419/153799>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*



EUROPEAN CENTRAL BANK

EUROSYSTEM

**WORKING PAPER SERIES**

**NO 1365 / AUGUST 2011**

**UNDERSTANDING  
AND FORECASTING  
AGGREGATE AND  
DISAGGREGATE  
PRICE DYNAMICS**

by Colin Bermingham  
and Antonello D'Agostino



EUROPEAN CENTRAL BANK

EUROSYSTEM



In 2011 all ECB publications feature a motif taken from the €100 banknote.



## WORKING PAPER SERIES

NO 1365 / AUGUST 2011

# UNDERSTANDING AND FORECASTING AGGREGATE AND DISAGGREGATE PRICE DYNAMICS<sup>1</sup>

by Colin Bermingham<sup>2</sup>  
and Antonello D'Agostino<sup>3</sup>

NOTE: This Working Paper should not be reported as representing the views of the European Central Bank (ECB). The views expressed are those of the authors and do not necessarily reflect those of the ECB.

This paper can be downloaded without charge from <http://www.ecb.europa.eu> or from the Social Science Research Network electronic library at [http://ssrn.com/abstract\\_id=1894592](http://ssrn.com/abstract_id=1894592).

<sup>1</sup> The views expressed in this paper are those of the authors, and do not necessarily reflect those of the Central Bank of Ireland.

<sup>2</sup> Corresponding author: Central Bank of Ireland, Dame Street, Dublin 2, Ireland; e-mail: [colin.bermingham@centralbank.ie](mailto:colin.bermingham@centralbank.ie)

<sup>3</sup> European Central Bank, Kaiserstrasse 29, D-60311 Frankfurt am Main, Germany, e-mail: [antonello.dagostino@ecb.europa.eu](mailto:antonello.dagostino@ecb.europa.eu) and Central Bank of Ireland.

© European Central Bank, 2011

**Address**

Kaiserstrasse 29  
60311 Frankfurt am Main, Germany

**Postal address**

Postfach 16 03 19  
60066 Frankfurt am Main, Germany

**Telephone**

+49 69 1344 0

**Internet**

<http://www.ecb.europa.eu>

**Fax**

+49 69 1344 6000

*All rights reserved.*

*Any reproduction, publication and reprint in the form of a different publication, whether printed or produced electronically, in whole or in part, is permitted only with the explicit written authorisation of the ECB or the authors.*

*Information on all of the papers published in the ECB Working Paper Series can be found on the ECB's website, <http://www.ecb.europa.eu/pub/scientific/wps/date/html/index.en.html>*

ISSN 1725-2806 (online)

# CONTENTS

Abstract	4
Non-technical summary	5
1 Introduction	6
2 Literature review	6
3 Data	8
3.1 US data	8
3.2 EA data	11
4 Data transformation and models specification	11
5 Results	14
5.1 AR	14
5.2 FAAR	15
5.3 BVAR	17
5.4 Alternative model for US data	18
6 Summary and conclusions	20
References	20
Tables	23
Appendix	27

## Abstract

The issue of forecast aggregation is to determine whether it is better to forecast a series directly or instead construct forecasts of its components and then sum these component forecasts. Notwithstanding some underlying theoretical results, it is generally accepted that forecast aggregation is an empirical issue. Empirical results in the literature often go unexplained. This leaves forecasters in the dark when confronted with the option of forecast aggregation. We take our empirical exercise a step further by considering the underlying issues in more detail. We analyse two price datasets, one for the United States and one for the Euro Area, which have distinctive dynamics and provide a guide to model choice. We also consider multiple levels of aggregation for each dataset. The models include an autoregressive model, a factor augmented autoregressive model, a large Bayesian VAR and a time-varying model with stochastic volatility. We find that once the appropriate model has been found, forecast aggregation can significantly improve forecast performance. These results are robust to the choice of data transformation.

JEL Classification: E17, E31, C11, C38.

Keywords: Aggregation, Forecasting, Inflation.

## Non-technical summary

The issue of forecast aggregation is to determine whether it is better to forecast a series directly or instead construct forecasts of its components and then sum these component forecasts. Notwithstanding some underlying theoretical results, it is generally accepted that forecast aggregation is an empirical issue. We conduct empirical exercises and relate our findings back to the properties of the dataset and the models used. The exercise is conducted on both United States (US) and Euro Area (EA) inflation. Although both datasets relate to inflation, these datasets have distinct characteristics and we tailor the model to the properties of the data. In all the empirical exercises in this paper, forecast aggregation leads to better forecasts. The aggregate forecast often has the least satisfactory performance and this makes the argument for aggregation more compelling given that multiple levels of aggregation are used.

The performance of the aggregated forecasts depends on the type of model used. In particular, the model must capture the key characteristics of the data. There is strong comovement in US inflation. Simple AR models do not perform very well in this context but multivariate models such as factor models and BVAR models that can capture this common movement or pick up feedback between the series have more accurate forecasts. For the Euro Area inflation rate, there is far less commonality and the series have more individual dynamics. Simple AR models tend to work well for this type of dataset. They have more accurate forecasts than both the benchmark and their multivariate counterparts.

The exercises are mainly based on multistep forecasts of year-on-year inflation rates. For US inflation, we forecast the  $h$ -quarter price change for  $h = 1, \dots, 8$  and find the results are robust to this change in the target forecast variable. We also introduce a time-varying model with stochastic volatility where forecasts are constructed iteratively. The time-varying model in conjunction with forecast aggregation leads to further improvements in forecast power. These robustness checks corroborate the main results in favour of forecast aggregation. The paper provides a substantive endorsement of the forecast aggregation approach, particularly in terms of inflation. The key to realising gains in terms of forecast aggregation lies in the ability to uncover the appropriate model for a particular dataset.

# 1 Introduction

When forecasting economic variables, one is often faced with the choice of either forecasting an aggregate directly or forecasting its components and then summing the component forecasts. This is frequently encountered when forecasting inflation, where prices are commonly available for a large number of components series in addition to the aggregate price index. The aggregation issue is a major practical consideration when it comes to forecasting key economic indicators but frequently forecasters are in the dark in terms of which approach is likely to yield the best results. There is a considerable set-up cost when estimating models on disaggregate data if there are a large number of component series so researchers are understandably reluctant to pursue this strategy unless it is likely to yield benefits.

Arguably, the literature on forecast aggregation is at an impasse. The early contributions focussed on deriving theoretical results but this approach was eventually abandoned as the underlying assumptions were too restrictive. Empirical papers tend to focus on a specific application. Competing sets of forecasts are constructed for a given country or set of countries to see whether forecast aggregation helps. With the exception of Hubrich (2003), few papers offer potential explanations of why the forecast aggregation strategy was a success or failure so there is little guidance to forecasters faced with the option of combining disaggregate forecasts.

We conduct empirical exercises but relate our findings back to the properties of the dataset and the models used. The exercise is conducted on both United States (US) and Euro Area (EA) inflation. Although both datasets relate to inflation, these datasets have distinct characteristics and we tailor the model to the properties of the data. In contrast to most previous studies, we consider multiple levels of aggregation for each dataset. We find that, once the appropriate model is found for a dataset, forecast aggregation always leads to improvements in forecast accuracy - the critical issue is to find the appropriate model. Frequently, the forecast based on the aggregate results in the worst forecast performance. This story is consistent with the theoretical literature. By providing a detailed explanation for main factors driving results for both datasets, we provide a greater understanding of the key issues relative to other empirical papers. In the next section, we provide a summary of the main contributions in both the theoretical and empirical side of the literature. Section 3 describes the data used for the empirical exercises. Section 4 outlines the notation and the models used in the paper with the results reported in section 5. Section 6 concludes the paper.

## 2 Literature Review

Early contributions in the area of forecast aggregation were mainly confined to theoretical results based on an assumed data generating process (DGP). Assuming that the components are ARIMA processes, Rose (1977) examines the DGP and forecasts for an aggregate of these models. Others including Tiao and Guttman (1980), Kohn



(1982) and Luetkepohl (1984a, 1984b) followed this approach with the DGP or forecast performance of the aggregated process related to an assumed structure for the DGP of the components. Based on asymptotic theory, it is possible to state that the disaggregate forecast will have a lower forecast error if the DGPs of all components are known. Luetkepohl (1984a) acknowledges that the superiority of the disaggregate forecast is no longer assured if the DGPs aren't known and instead must be estimated. In practice, DGPs are not known to forecasters so the results of these studies provide the starting point to investigations of forecast aggregation but the question of forecast aggregation has a strong empirical element.

European Monetary Union (EMU) revived interest in the topic of forecast aggregation but given the limited success of the theoretical approach, the literature changed direction and empirical exercises became much more common. There have been two distinct approaches adopted. The traditional approach, which is followed in this paper, is to construct forecasts of the disaggregates and combine them. In a couple of recent papers, Hendry and Hubrich (2006, 2010) suggest the alternative route of including disaggregates directly in the model of the aggregate. These two papers consider both predictability in population and forecastability in sample through both analytical and empirical work. The first paper proposes the idea of using disaggregates in the equation for the aggregate and shows through some theoretical results that including disaggregates increases predictability. Whether this translates into greater forecast accuracy depends on practical issues such as model selection, estimation uncertainty, structural breaks and changing collinearity between disaggregate series. In the empirical section, it is found that using disaggregate information does not help a great deal forecasting euro area inflation, although the exercise is hampered somewhat by the shortness of the data span available. In contrast, US results based on longer sample support the inclusion of disaggregate data.

The second paper considers the impact of changing coefficients, mis-specification, estimation uncertainty and measurement error. It builds on the first paper by putting all the practical factors that impact on actual forecast performance in a theoretical framework. This is further backed up by Monte Carlo simulations and empirical exercises featuring US data. This paper highlights the key role played by estimation uncertainty in determining practical forecast performance and the consequent role for model selection procedures. Luetkepohl (2010) includes practical exercises that also follow the same approach as Hendry and Hubrich (2006, 2010). Systems of VARs are estimated which include both aggregate and disaggregate information for employment and inflation in the Euro Area. Luetkepohl finds that although taking disaggregate information into account should theoretically improve forecasts, the inclusion of too many disaggregates can result in estimation error and specification error which ultimately leads to an efficiency loss.

This paper is concerned with the traditional approach, which is the focus of much of the literature. Hubrich (2003) is one of the first studies to examine Euro Area HICP inflation in this context. Forecasts are constructed both directly and by summing

forecasts for the five main subcomponents. Models used include random walk forecasts, univariate forecasts and VAR forecasts. The study concludes that there is little benefit to forecast aggregation but the data only span Jan '92 - Dec '01 so estimation error may have played a role in this result. Benalal et al (2004) again examines HICP forecasts for the Euro Area but this time forecasts are aggregated both by country and by commodity group. Models include the random walk, ARIMA, exponential smoothing, VAR and BVAR. The results do not show any systematic benefit to forecast aggregation but the span of data is again quite short.

In country specific studies of HICP inflation, Duarte and Rua (2005), Bruneau et al (2007) and Moser et al (2007) all find forecast aggregation leads to improved forecasts for inflation for Portugal, France and Austria respectively. The models used in these papers are again popular time series models but the spans of data available are longer than those from the earlier Euro Area studies. While the different conclusions reached are difficult to reconcile completely, the short span of data for the early studies could be an important factor given the importance attributed to estimation error by Hendry and Hubrich (2010).

Turning briefly to some other studies, forecast aggregation has also been examined in the context of output forecasting. Zellner and Tobias (2000) forecast the aggregate growth rate of 18 industrial countries using an aggregate and disaggregate approach. They report improved forecasts from the disaggregate approach. Marcellino, Stock and Watson (2003) forecast prices and three activity measures for the euro area directly and by aggregating country specific models. They find forecasts are more accurate when country specific models are aggregated. Thus, although there is not a full consensus, the empirical work on forecast aggregation is broadly supportive of the idea that aggregating forecasts can lead to improvements in accuracy.

The aim of this paper is to look into the issue of forecast aggregation in greater detail than the existing literature. We utilise multiple levels of disaggregate data for each dataset and a number of different models (autoregressive (AR), factor augmented AR, Bayesian Vector Autoregression (VAR) with Minnesota priors and time varying VAR). This allows us to explore the properties of the data which lead to benefits in terms of forecast aggregation. By considering two separate datasets with different characteristics, we are also able to highlight the importance that the selection of the correct model type has on the results. These insights are valuable to other forecasters contemplating the aggregation approach.

## 3 Data

### 3.1 US Data

The analysis in this paper draws on both US data and EA data. The US series are NIPA data from the Bureau of Economic Analysis (BEA).<sup>1</sup> The price series are personal

---

<sup>1</sup>Available at: <http://www.bea.gov/national/nipaweb/SelectTable.asp>

consumption expenditures available quarterly from 1959Q1 - 2009Q4. The data are already available at different levels of aggregation. This paper considers four different levels of aggregation for the dataset. The first is a three item breakdown which includes the prices of durable goods, non-durable goods and services. We next consider a fifteen item breakdown. The price categories are still quite broad at this level of aggregation and examples include food, housing and transport. A full list of price series for all levels of aggregation is provided in the Table 1. The third breakdown consists of fifty different price series. The categories here are quite narrowly defined and again are presented in Table 1. The final breakdown is based on 169 series. The series are too numerous to list in the Table but a list of included items is available upon request.

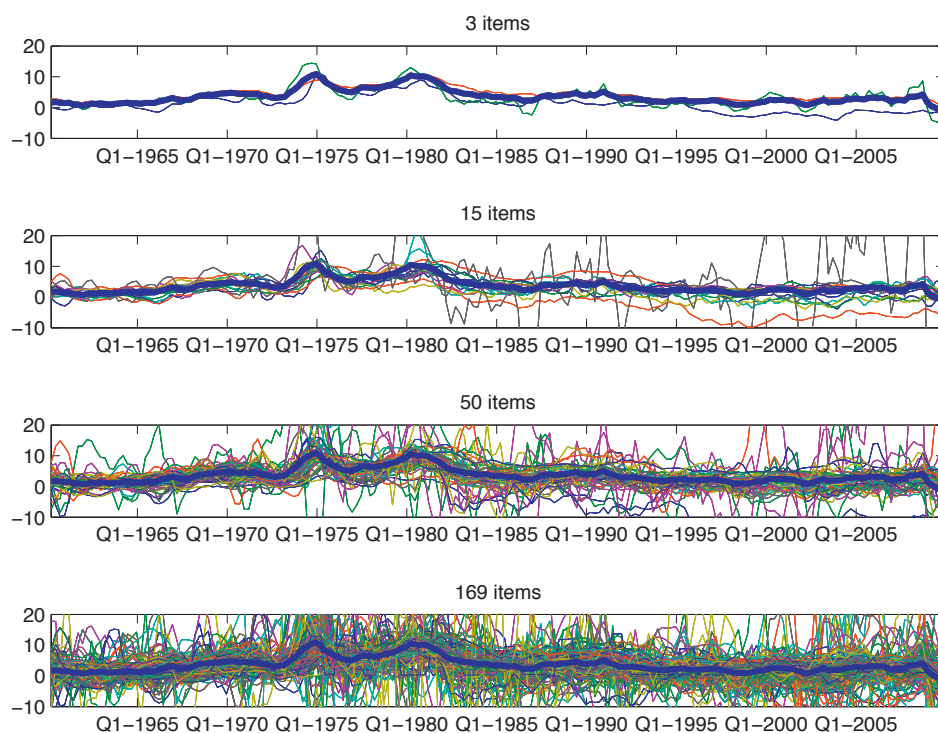
As we wish to compare aggregated individual forecasts with the forecasts from the overall PCE inflation rate, we must be able to construct the PCE inflation rate from the individual inflation rates as a first step. This requires the weights of each item for each level of aggregation. All data are taken from Tables 2.4.4U, 2.4.5U and 2.4.6U on the BEA website. The price series are chained index values and their weights are calculated according to the approximation provided in Dolmas (2006):

$$w_{i,t+1} = \frac{1}{2} \frac{Q_{i,t}P_{i,t}}{\sum Q_{i,t}P_{i,t}} + \frac{1}{2} \frac{Q_{i,t+1}P_{i,t}}{\sum Q_{i,t+1}P_{i,t}}$$

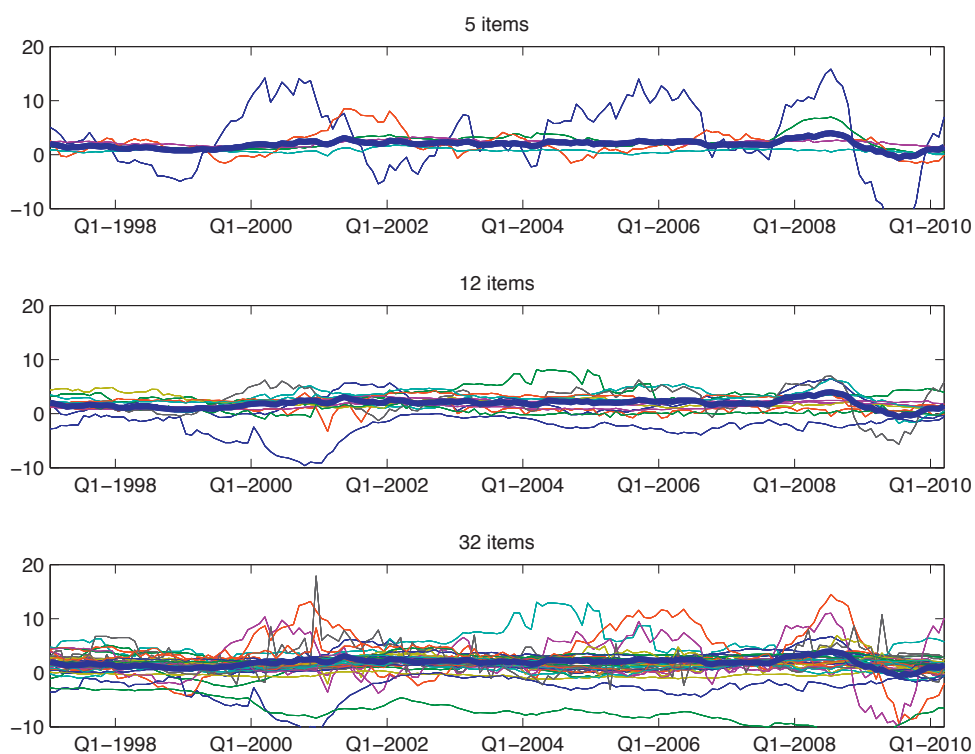
The weight at time  $t+1$  is equal to an average of the expenditure share of the product at time  $t$  and its expenditure share had consumers bought the  $t + 1$  quantity at time  $t$  prices. In each case, the accuracy of this approximation was checked by constructing the aggregate inflation rate from the components. The aggregate inflation rate was recovered with a high level of precision, which ensures the validity of the empirical exercise.

Figure 1 graphs the Year on Year (YoY) PCE inflation rate and its component inflation rates for each of the four different levels of aggregation used in the paper. In each graph, the thick blue line is the aggregate inflation rate. For the graph of the 3 items, the individual items move in tandem with the PCE inflation rate. As the number of items in each breakdown increases, the series obviously have more individual dynamics although there is still quite noticeable comovement with the PCE rate, indicated by the tight bunching of series around the PCE inflation rate.

**Figure 1: PCE Inflation and its Component Inflation Rates**



**Figure 2: HICP Inflation and its Component Inflation Rates**



## 3.2 EA Data

The euro area data are price series for the Harmonized Index of Consumer Prices (HICP). The series along with their weights are available on the Eurostat website.<sup>2</sup> The series are disaggregated at three different levels with a 5-item, 12-item and 32-item breakdown. The items included in each level of aggregation are also presented in Table 1. The series are monthly and the sample period is from January 1996 to December 2009. Although it is possible to get data at a more detailed level over the latter part of the sample, it is not possible to do so for the entire sample so the 32-item breakdown represents the most detailed available for our purposes.

There is a strong seasonal pattern in some of the euro area data when month-on-month growth rates are calculated. Seasonally adjusted data are not available. In addition, the seasonal pattern is not stable over the sample and so it not possible to estimate a consistent seasonally adjusted series. To mitigate this problem, estimation is conducted using year-on-year growth rates. Seasonality is not an issue with the US data as all series are seasonally adjusted.

Figure 2 graphs the YoY HICP inflation rate and the component rates at the three levels of aggregation used. At the five item level, the series display more heterogeneous dynamics relative to the US data. This pattern is repeated with the 12 and 32 item datasets. Although there is bunching around the aggregate, these series have stronger individual characteristics than the US data. This is probably due to the fact that the US data are from one country whereas the EA data combines the inflation rates of several different countries.

## 4 Data Transformation and Models Specification

The empirical exercise in this paper is addressed in the following way: we construct one set of forecasts by estimating models on the aggregate series and a second set by using the same model to forecast the individual series prior to aggregation, then we compare the accuracy of both approaches. The target variable is the aggregate, annualized  $h$  period inflation, defined as  $\pi_t^h = k \log(\frac{P_t}{P_{t-h}})$ , where the constant  $k$  is the normalization term.<sup>3</sup>  $P_t$  is the aggregate level of price index. Given a model  $m$ , we perform a pseudo out-of-sample forecasting simulation. At time  $t$ , we estimate the parameters of the model and compute the forecasts of the aggregate and disaggregate inflation series at horizon  $h$ , then we update the sample with a new observation and, at time  $t+1$ , we re-estimate the parameters of the model and compute again the forecasts for time  $t+1+h$ . This pseudo out-of-sample forecasting exercise is iterated up to the end of the sample for each type of model. This exercise is not a real time exercise. However, as we only use inflation rates for each dataset, the series are all published with the same lag. In addition, the inflation rates in both datasets are not subject

<sup>2</sup> Available at [http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search\\_database](http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database)

<sup>3</sup> It is  $\frac{400}{h}$  in the case of quarterly data and  $\frac{1200}{h}$  in the case of monthly data.



to a significant degree of revision. From this perspective, we argue that this exercise provides a realistic appraisal of aggregate versus disaggregate forecasting.

Forecasts of the target variable at horizon  $h$  are denoted as  $\hat{\pi}_{a,t+h|t}^{h,m}$ , when they are computed directly on the aggregate inflation series, and as  $\hat{\pi}_{d,t+h|t}^{h,m} = \sum_{j=1}^{N_s} w_{j,t} \hat{\pi}_{j,t+h|t}^{h,m}$  when they are computed by aggregating forecasts of disaggregate inflation series  $j$ .<sup>4</sup> The first subscripts  $a$  or  $d$  denote if the forecast of the target variables is computed with the aggregate or disaggregate inflation series respectively, while  $t+h|t$  refers to the fact that, for horizon  $h$ , forecasts are computed by using information up to time  $t$ . Finally, the first superscript  $h$  denotes the transformation adopted for prices, while  $m$  refers to the model employed.

We will use the following models:

#### Atkeson Ohanian Model (AO) (2001)

$$\pi_{t+h}^h = \pi_t^h + \omega_{t+h}^h \quad (1)$$

The forecast at  $t+h$  is computed as:

$$\hat{\pi}_{a,t+h|t}^{h,AO} = \pi_t^h \quad (2)$$

#### AutoRegressive Model (AR)

For a generic inflation series  $j$ :

$$\pi_{j,t+h}^h = \alpha_j^h + B_j^h(L)\pi_{j,t}^h + \varepsilon_{j,t+h}^h \quad (3)$$

where  $B_j^h(L) = B_{j,0}^h + \dots + B_{j,s}^h L^s$  is a polynomial in the lag operator  $L$ . Parameters are estimated by Ordinary Least Squares (OLS). The forecast for a given horizon  $h$  is computed as:

$$\hat{\pi}_{j,t+h|t}^{h,AR} = \hat{\alpha}_j^h + \hat{B}_j^h(L)\pi_{j,t}^h \quad (4)$$

#### Factor Augmented AutoRegressive Model (FAAR)

$$\pi_{j,t+h}^h = \nu_j^h + C_j^h(L)\pi_{j,t}^h + \gamma^h F_t + \zeta_{j,t+h}^h \quad (5)$$

This is the AR model of eq.(3) augmented with one factor. The factor is estimated with the first principal component (Stock and Watson, 2002) computed on the most detailed data set available. For example, the factor for the US dataset is computed on the dataset of 169 series, while that for the Euro area is computed on the dataset of 32 series. Parameters of eq.(5) are estimated by OLS. The forecast at horizon  $h$  is given by:

$$\hat{\pi}_{j,t+h|t}^{h,FAAR} = \hat{\nu}_j^h + \hat{C}_j^h(L)\pi_{j,t}^h + \hat{\gamma}^h \hat{F}_t \quad (6)$$

<sup>4</sup> $N_s$  is the number of series in the  $sth$  set of disaggregate series;  $s = \{1, 2, 3, 4\}$  in the case of US dataset and  $s = \{1, 2, 3\}$  in the case of Euro area dataset.

## Bayesian VAR (BVAR)

This is a Bayesian VAR with the Minnesota prior as proposed by Banbura, Giannone and Reichlin (2010). Let's denote with  $P_{j,t}$ , the price level for series  $j \in S_i$ , where  $S_i = \{1, \dots, j, \dots, n_i\}$ ; the model is estimated on the log-level of the series denoted as  $p_{S_i,t}$ :

$$p_{S_i,t} = c + A_1 p_{S_i,t-1} + \dots + A_p p_{S_i,t-p} + v_t \quad (7)$$

where  $p_{S_i,t}$  is a  $(S_i \times 1)$  vector of variables,  $c$  is a  $(S_i \times 1)$  vector of constants,  $A_1 \dots A_p$  are  $(S_i \times S_i)$  matrices of coefficients and  $v_t$  is a  $(S_i \times 1)$  vector of disturbances. The estimation of the model for a large set of variables is unfeasible due to the curse of dimensionality.

One solution is to impose restrictions (prior beliefs) on the parameters of the system. Following Banbura, Giannone and Reichlin (2010) we impose Litterman (1986) priors. The coefficients of a matrix  $A_i$ ,  $i = 1, \dots, p$  are normally distributed random variables with the mean of the coefficient matrix on the first lag (matrix  $A_1$ ) equal to an identity matrix  $I_{S_i}$  and the mean of all the other coefficients equal to zero. The variance of the parameters depends on a parameter  $\tau$  which defines the tightness of the priors. A value of  $\tau$  equal to zero exactly imposes the random walk with drift model on the variables, while a value of  $\tau$  bigger than zero allows for some variability around the mean of the coefficients and the random walk prior is not exactly imposed.<sup>5</sup> We impose also another type of prior, on the sum of coefficients of the matrices  $A_1 \dots A_p$ . This prior is imposed by means of another parameter  $\mu$ . If  $A_1 + \dots + A_p = I_{n_i}$  the prior is imposed exactly and the specification is equivalent to a VAR in first differences. This will imply that the forecasts will converge to the variable's growth rate.

A forecast of the log level of series  $j$  at horizon  $h$  is then computed as:

$$\hat{p}_{S_i,t+h|t} = \hat{c} + \hat{A}_1 \hat{p}_{S_i,t+h-1|t} + \dots + \hat{A}_p \hat{p}_{S_i,t+h-p|t} \quad (8)$$

where  $\hat{p}_{S_i,t+h-i|t} = p_{S_i,t+h-i}$  if  $i \geq h$ . In practice, the forecast at time  $t+h$  is computed recursively from the forecast at time  $t+1$ . The estimates of the parameters correspond to the median of the posterior distributions. For each series  $j \in S_i$ , the annualized  $h$  period inflation rate is computed as:

$$\hat{\pi}_{j,t+h|t}^{h,BVAR} = (\hat{p}_{j,t+h|t} - p_{j,t})k \quad (9)$$

The maximum lag length for the AR model is specified ex ante and the actual lag length is chosen according to the Bayes Information Criterion (BIC), while the lag specification for the BVAR is selected by choosing the number of lags that minimize the squared forecast errors of the previous period, including a minimum of 5 lags for the quarterly dataset and a minimum of 13 lags for the monthly dataset. The values of the hyperparameters,  $\mu$  and  $\tau$  are chosen on a grid search so that the fitted model has an  $R^2$  as close as possible to 50%. This ensures a reasonable in-sample fit but guards against over-fitting, which leads to poor out-of-sample forecasts.

<sup>5</sup>A scale parameter, to fix the variance of the coefficients, is set by estimating the variance of the residuals from a univariate model of order  $p$  on the single variables  $p_{j,t}$ .

## Recursive Strategy for all Models

The first estimation sample (prior to data transformations) for US data is 1959:Q1-1995:Q2 with forecasts beginning from 1995:Q2+1 to 1995:Q2+h. This is the earliest sample for which weights are available. Final recursive forecasts are computed up to 2009:Q4. For the EA data, the first estimation sample is 1996:M1-2001:M12 and the forecast begins in 2001:M12+1 to 2001:M12+h. The final recursive forecasts end in 2009:M12. Forecast accuracy is evaluated through the Mean Square Forecast Error (MSFE) statistic, however, to facilitate the comparison, the accuracy of a model  $m$  is compared (ratio) with that obtained by the Atkeson-Ohanian random walk model, used as the benchmark. Finally, as already mentioned above, some series in the EA dataset are characterized by strong seasonal patterns. To mitigate seasonality the exercise is performed on the year-on-year data transformation. *Eq.(3)* for example is modified as follows:

$$\pi_{j,t+h|t}^4 = \alpha_j^4 + B_j^4(L)\pi_{j,t}^4 + \varepsilon_{j,t+h}^4$$

where the superscript 4 refers to the data transformation.<sup>6</sup> It is not possible to seasonally adjust the Euro Area dataset. The weights that are provided by Eurostat could not be used to construct the aggregate from the component series if the series are transformed. In addition, the seasonal pattern of the series appears to change over the sample and so a portion of the residuals of the seasonally adjusted series fail standard statistical tests.

## 5 Results

### 5.1 AR

The numbers in Table 2 are ratios of the RMSE from the AR model relative to the AO benchmark, with a value less than one indicating the forecast model outperforms the benchmark at the specified horizon. The one and two star superscripts denote a statistically significant improvement in forecast performance relative to the benchmark at the 5% and 10% levels respectively. Due to the nested nature of the models, we use the test statistic proposed by Clark and West (2007). The first part of the table shows the results for the United States. When an AR model is used to forecast the aggregate directly, it is only possible to improve upon the benchmark at the one-quarter horizon. Forecast performance relative to the benchmark gets relatively worse as the horizon increases. When AR models are applied to the disaggregates and combined, the forecasts are improved. The AR model based on the 15-item aggregation provides the best forecasts, as they outperform the benchmark up to 5 quarters ahead. This information is also presented in graphical format in Figure 3. It clearly shows how poorly the aggregate forecast performs relative to the disaggregates over most of the horizon. Another feature evident from the graph is that the greatest gains in forecast accuracy are given by the 3-item and 15-item breakdown. Forecast accuracy decreases, particularly over longer horizons, when the 50-item and 169-item breakdown are used.

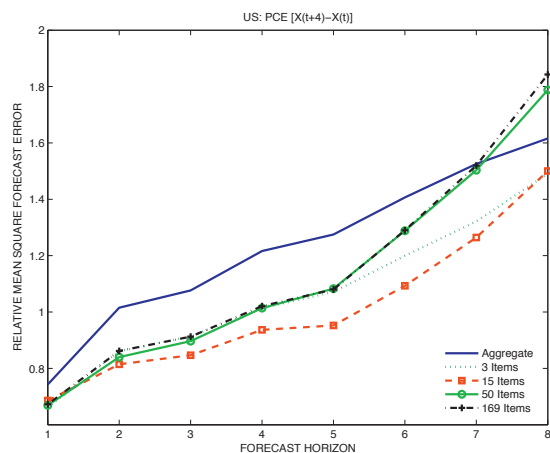
---

<sup>6</sup>As robustness check, in the last section of the paper, we report a set of results for an alternative price transformation (for the US dataset).

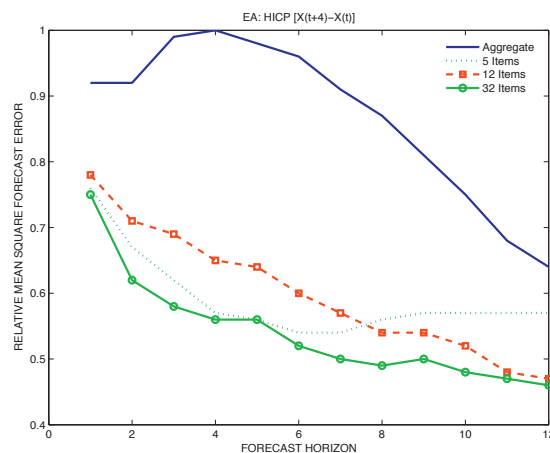


Considering the US AR model in isolation, any gains in forecasting the disaggregates have already been exploited when the 15-item breakdown is used.

**Figure 3: RMSFE of AR Models versus AO (US-YoY)**



**Figure 4: RMSFE of AR Models versus AO (EA-YoY)**



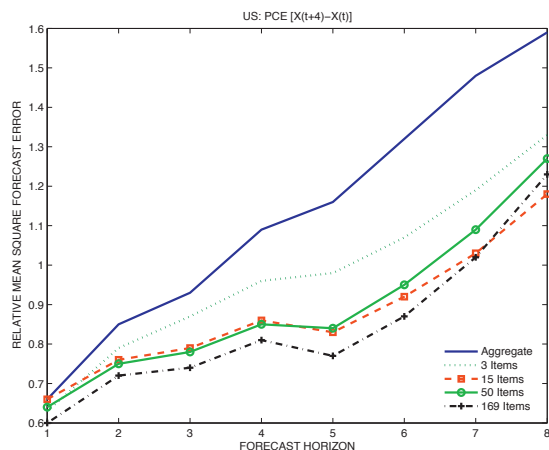
The second part of Table 2 presents the results for the Euro Area. The horizon is now twelve months rather than eight quarters and there are only three levels of aggregation rather than four. The results here differ from the US results in a number of ways. The forecasts here are better than the US forecasts in the sense that improvements relative to the benchmark are much greater. Furthermore, the greatest gains relative to the benchmark are at the longer horizons for the Euro Area whereas the US model forecasts have their greatest gains at the shorter horizons. This behavior is largely explained by the performance of the benchmark. The HICP is not as persistent as the PCE inflation rate. Consequently, the AO benchmark is not as good for the Euro Area, particularly at longer horizons. The key messages are the same as for the US however. The results in the table again show that the aggregate performs poorly relative to the disaggregates. The 32-item breakdown results in the best forecasts. The results are also graphed in Figure 4 and the difference in the performance of the aggregate relative to the disaggregates is quite stark.

## 5.2 FAAR

The first section of Table 3 documents the forecast performance for the US when a factor is included in the forecast equation. The aggregate now improves upon the benchmark when forecasting up to three quarters in the future. The aggregate forecast still has the least satisfactory performance however, which is also evident graphically in Figure 5. The model based on 169 disaggregates now has the best forecast performance over most horizons. The factor forecasts outperform the simple AR model so that the best forecasts overall for US inflation come from the 169-item model. The EA results with the FAAR are remarkably similar to those for the AR model. The aggregate forecast is strongly outperformed by the disaggregates, with the 32-item breakdown yielding the best results and this pattern is clearly evident in Figure 6. The results of

Tables 2 and 3 are supportive of forecast aggregation, with the most accurate forecasts coming from disaggregate models.

**Figure 5: RMSFE of FAAR Model versus AO (US-YoY)**



**Figure 6: RMSFE of FAAR Model versus AO (EA-YoY)**

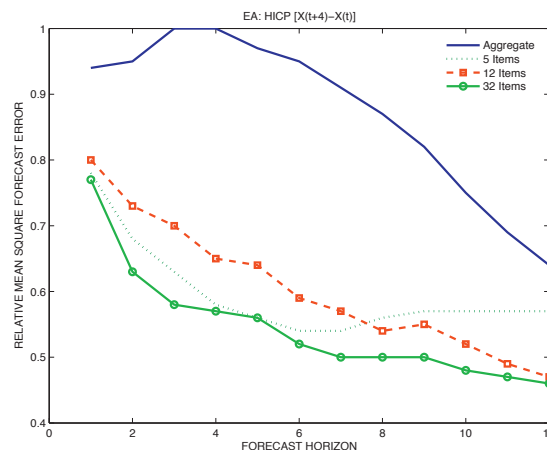


Table 4 documents the change in forecast accuracy when the factor is added to the forecasting equation. There are universal improvements in forecast accuracy for the US data. In addition, the forecasts based on the most detailed breakdown enjoy the greatest improvements in forecast performance. In contrast, for the EA models, the inclusion of the factor leads to virtually no change in the forecasts. To examine the reasons for this, we examine the structure of the dataset to see if there is a large common element to the series. Firstly, we regress the individual series on the factor alone and report the average  $R^2$  in Table 5. We also calculate the average correlation between the series. There is strong commonality in the US PCE dataset. One factor explains 85% of the variation in the aggregate series. The average  $R^2$  declines in line with the number of disaggregates but even at the 169-item level, the average  $R^2$  is 30%. Similarly, the average correlation between the series is high at this level. Commonality is much lower for the euro area inflation series. One factor only explains 37% of the variation in the aggregate series. This drops to about 20% for the disaggregates. Similarly, the average correlation between the series is low.

The strong common element in the US dataset is picked up by the factor model. The simple AR model which excludes the factor is, therefore, mis-specified via the omission of a relevant variable. This will have the usual effect of creating a bias in the coefficients, which will obviously impact the forecasts. Although not reported, the correlation amongst the residuals for the US AR models was found to be far higher than their EA counterparts, as the common factor was captured by the residuals and this imparted much stronger correlation. As described earlier, higher correlation amongst the disaggregate residuals is not good for forecasting, as it leads to forecast errors bunching in a particular direction. This underlying structure in the datasets explains why the factor needs to be included for the US models but not for the EA models.

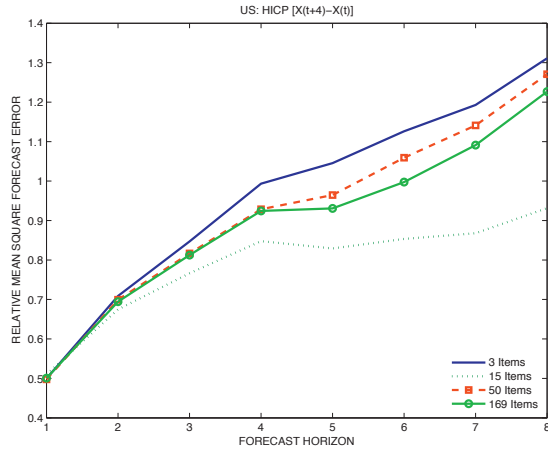
The one outstanding issue is why the forecasts based on more detailed data improve to a greater extent. The aggregate and 3-item US FAAR models have very modest improvements in forecast power relative to their AR counterparts. The PCE aggregate and the 3-item inflation rates are a weighted average of a large number of underlying inflation rates. Similarly, the factor is a weighted average of all inflation rates. Although the factor weights are calculated to satisfy a maximum variance criterion, the aggregate inflation rate and the 3-item inflation rates are much like factors as they pick up a lot of the commonality in the data. Consequently, the aggregate and 3-item AR models are effectively modelling the common component. Thus, improvements over the AR model are relatively modest when the factor is added as the factor and AR series both model the same component of the data. At the more detailed levels of aggregation, the AR component can pick up the stronger individual dynamics while the factor picks up the common element, which is still meaningful even for the 169-item breakdown. The AR component and the factor are now modelling different behaviour. This is why forecast improvements are greater for the detailed breakdown. This demonstrates the interplay between model choice and the level of aggregation in the data.

### 5.3 BVAR

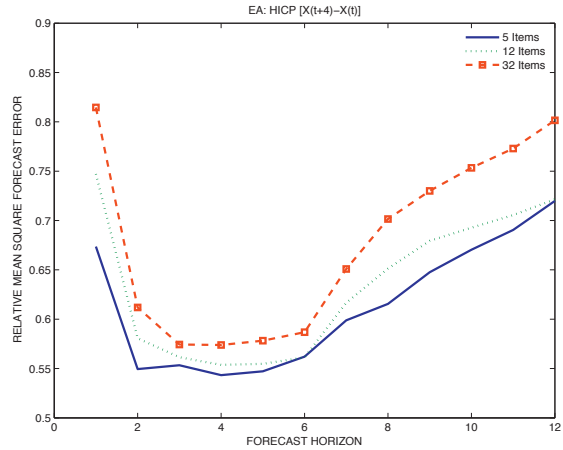
Table 6 presents the results of the BVAR model. The US results show that the BVAR is also a fruitful way to exploit the dynamic properties of the data, with the forecast errors again much smaller than those from the standard AR model, particularly for short horizon forecasts. In comparison with the factor model, the BVAR tends to perform better for the short horizons and the factor model does better over the longer horizons. By averaging first by horizon and then by level of aggregation, we find that the BVAR forecasts are equally accurate to the factor model forecasts. The exception to this pattern is the 15-item BVAR, which outperforms the 15-item factor forecast over all horizons. The best individual forecast of all forecast methods considered to date is also the 15-item BVAR, which is 6% more accurate than the best FAAR model, when averaged by horizon. This is the only model which is more accurate than the benchmark at all horizons, although the improvement is not statistically significant at quarter 8. Figure 7 graphs the performance of the BVAR models for the US and the superiority of the 15-item specification is clear.

The best BVAR model for the EA is the 5-item model, which is depicted in Figure 8. However, the results for the EA show that the BVAR fails to improve on the simple AR model. The strong individual dynamics of the series for the HICP means that the simple AR model provides the best forecast. Any attempt to capture common comovement or feedback between the series does not improve the forecasts. The BVAR forecasts are also weaker than the factor model, due to a drop in accuracy for the longer horizons but this is of less significance here as both are outperformed by the AR model.

**Figure 7: RMSFE of BVAR Model  
versus AO (US-YoY)**



**Figure 8: RMSFE of BVAR Model  
Model versus AO (EA-YoY)**



In summary, we have found that the 32-item AR model works best for the Euro Area. In the absence of strong comovement among the series, the AR model is appropriate as there is no omitted variable bias or tendency for the forecast errors to group in the positive or negative directions. For the US, there is a need to model the common component of the series. Without this, there is omitted variable bias and forecast errors will cluster, reducing the chances of getting off-setting errors. This is why the factor model and BVAR models work. For low levels of aggregation, the factor models don't improve upon the AR model greatly given the collinearity between the factors and the AR component. Once we allow for more a detailed breakdown of inflation, the AR components and factor model different components and the common element is modelled in a parsimonious way.

### 5.4 Alternative Model for US Data

As a robustness check, we consider one alternative model for the US. Given the seasonality issues in the Euro Area dataset, our attention is limited to the US because this model constructs forecasts iteratively using quarter-on-quarter growth. The final type of model considered is a time-varying parameter AR model with stochastic volatility (TV-AR). D'Agostino et al (2009) estimate a TV-AR model for three macro variables in the U.S and find it does particularly well at forecasting inflation. The computational cost of estimating the TV-AR model means that it is only likely to be applied to a small number of items in practice. For this reason, we only conduct a partial exercise in which we estimate the model for the 15-item breakdown. The BVAR with 15 items is the most accurate model so it is instructive to use this as a comparator. We assume that:

$$\pi_{j,t}^1 = \delta_{j,t} + \rho_{1,t}\pi_{j,t-1}^1 + \dots + \rho_{p,t}\pi_{j,t-p}^1 + e_{j,t}^1 \tag{10}$$

where  $\delta_{j,t}$  is the time varying intercept,  $\rho_{i,t}$  with  $i = 1, \dots, p$  are time varying coefficients and  $e_{j,t}^1$  is a Gaussian white noise with zero mean and time-varying variance  $\sigma_t^2$ . We assume that  $\sigma_t$  evolves as geometric random walk, belonging to the class of models known as stochastic volatility.

$$\log(\sigma_t) = \log(\sigma_{t-1}) + u_t \quad (11)$$

Forecasts at time  $t + h$  are computed iteratively:

$$\hat{\pi}_{j,t+h|t}^1 = \hat{\delta}_{j,t} + \hat{\rho}_{1,t} \hat{\rho}_{j,t+h-1}^1 + \dots + \hat{\rho}_{p,t} \hat{\rho}_{j,t+h-p}^1 \quad (12)$$

where  $\hat{\pi}_{j,t+h-i}^1 = \pi_{j,t+h-i}^1$  if  $i \geq h$ . The estimates of the parameters correspond to the median of the posterior distributions.<sup>7</sup>

A technical issue arises when we generate multi-step expectations; we have to evaluate the future path of drifting parameters. We follow the literature and treat those parameters as if they had remained constant at the current level. See Sbordone and Cogley (2008) for a discussion of the implications of this simplifying assumption.

For each series  $j$ , forecasts are first cumulated to recover the  $h$  period inflation:

$$\hat{\pi}_{j,t+h|t}^{h,TV-AR} = \frac{1}{h} \sum_{s=1}^h \hat{\pi}_{j,t+s|t}^{1,TV-AR} \quad (13)$$

and are then aggregated to recover the forecast for the aggregate index:

$$\hat{\pi}_{d,t+h|t}^{h,TV-AR} = \sum_{j=1}^{N_s} w_{j,t} \hat{\pi}_{j,t+h|t}^{h,TV-AR} \quad (14)$$

The results for this exercise are presented in the first two columns of Table 10. As before, the first results column of the table shows the RMSE of the AO benchmark. The second column shows the forecasts errors of the TV-AR relative to the AO, with a value less than one indicating that the TV-AR has the better forecast. The third column compares the TV-AR to the BVAR. The results in the second column show that the forecast errors compare favourably to the benchmark over the entire forecast horizon. When compared to the BVAR, the TV-AR has more accurate forecasts over most horizons. The TV-AR does well for the short-term forecasts but its edge relative to the BVAR steadily declines to the point where the BVAR does better for quarters 7 and 8. Taken on average however, the TV-AR has the better performance with forecasts that are 6% more accurate on average over all horizons. The results demonstrate that combining forecast aggregation with time variation in the parameters and allowing for stochastic volatility can lead to even greater improvements in forecast performance. As the comparison for the TV-AR models is based on 15-items, we graph the results of the 15-item breakdown for all models in Figure 9.<sup>8</sup> It shows that the AR model is not appropriate for a dataset with these properties. There is a big improvement moving to the factor model and further improvements when the BVAR and TV-AR models are used.

<sup>7</sup>We fix  $\lambda_1 = \lambda_2 = 10e^{-0.2}$ . These are the tightness parameters governing the amount of time-variation in the coefficients and volatility respectively.

<sup>8</sup>Figure 9 is contained with other graphs at the end of the appendix.

## 6 Summary and Conclusions

In this paper, we conduct an empirical exercise to test if it is possible to achieve gains in forecast accuracy by forecasting the individual components of inflation and aggregating the individual forecasts relative to forecasting the aggregate inflation rate directly. The empirical exercise uses data on both United States and Euro Area inflation. These datasets are quite distinct and require a different modelling approach. We consider four levels of disaggregation for the United States and three for the Euro Area. In all the empirical exercises in this paper, forecast aggregation leads to better forecasts. The aggregate forecast often has the least satisfactory performance and this makes the argument for aggregation more compelling given that multiple levels of aggregation are used.

The performance of the aggregated forecasts also depends on the type of model used. In particular, the model must capture the key characteristics of the data. There is strong comovement in US inflation. Simple AR models do not perform very well in this context but multivariate models such as factor models and BVAR models that can capture this common movement or pick up feedback between the series have more accurate forecasts. For the Euro Area inflation rate, there is far less commonality and the series have more individual dynamics. Simple AR models tend to work well for this type of dataset. They have more accurate forecasts than both the benchmark and their multivariate counterparts. We also discuss the issue of estimation error. We suggest that persistent series should be subject to low estimation error as they can be parameterised parsimoniously.

The exercises are mainly based on multistep forecasts of year-on-year inflation rates. For US inflation, we forecast the  $h$ -quarter price change for  $h = 1, \dots, 8$  and find the results are robust to this change in the target forecast variable. We also introduce a time-varying model with stochastic volatility where forecasts are constructed iteratively. The time-varying model in conjunction with forecast aggregation leads to further improvements in forecast power. These robustness checks corroborate the main results in favour of forecast aggregation. The paper provides a substantive endorsement of the forecast aggregation approach, particularly in terms of inflation. The key to realising gains in terms of forecast aggregation lies in the ability to uncover the appropriate model for a particular dataset.

## References

- [24] Atkeson A. and L. Ohanian (2001): “Are Phillips Curve useful for forecasting Inflation”, Reserve Bank of Minneapolis, Quarterly Review, 25(1), Pages 2-11.
- [24] Banbura M., D. Giannone and L. Reichlin (2010): “Large Bayesian VARs”, Journal of Applied Econometrics, Vol. 25(1), pages 71-92,.

- [24] Benalal, N., Diaz del Hoyo, J. L., Landau, B., Roma, M. and Skudelny, F. (2004), “To aggregate or not to aggregate? euro area inflation forecasting”, *ECB Working Paper 374*.
- [24] Bruneau, C., De Bandt, O., Flageollet, A. & Michaux, E. (2007), “Forecasting inflation using economic indicators: The case of France”, *Journal of Forecasting*, Vol. 26, pp. 1 - 22.
- [24] Cogley, T., and A. M. Sbordone, (2008), “Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve”, *American Economic Review*, Vol. 98(5), pp. 2101-26.
- [24] Clark, T., and K. West, (2008), “Approximately normal tests for equal predictive accuracy in nested models”, *Journal of Econometrics*, Vol. 138, pp. 291-311.
- [24] D’Agostino, A., Gambetti, L. and Giannone, D. (2009), “Macroeconomic Forecasting and Structural Change”, *European Central Bank Working Paper No. 1167*.
- [24] Domlas, J. (2005), Commentary, *Federal Reserve Bank of Dallas Working Paper 0506*.
- [24] Duarte, C. and Rua, A. (2007), “Forecasting inflation through a bottom-up approach: How bottom is bottom?”, *Economic Modelling*, Vol. 24, No. 6, November 2007, pp. 941-953.
- [24] Enders, W. (2010), *Applied Econometric Time Series, 3rd Edition*, Wiley.
- [24] Hendry, D. F. and Hubrich, K. (2006), “Forecasting aggregates by disaggregates”, *European Central Bank Working Paper 589*.
- [24] Hendry, D. F. and Hubrich, K. (2010), “Combining disaggregate forecasts or combining disaggregate information to forecast an aggregate”, *Journal of Business and Economic Statistics*.
- [24] Hubrich, K. (2005), “Forecasting euro area inflation: Does aggregating forecasts by HICP component improve forecast accuracy?”, *International Journal of Forecasting*, Vol. 21, pp. 119-136.
- [24] Kohn, R. (1982), “When is an aggregate of a time series efficiently forecast by its past?”, *Journal of Econometrics*, Vol. 18, pp. 337-349.
- [24] Luetkepohl, H. (1984a), “Forecasting contemporaneously aggregated vector ARMA processes”, *Journal of Business and Economic Statistics*, Vol.2, No.3, pp. 201-214.
- [24] Luetkepohl, H. (1984b), “Linear transformations of vector ARMA processes”, *Journal of Econometrics*, Vol.26, pp. 283-293.
- [24] Luetkepohl, H. (2010), “Forecasting Non-linear Aggregates and Aggregates with Time-Varying Weights”, *EUI Working Paper*, No. 2010/11.

- [24] Marcellino, M., Stock, J. H. and Watson, M. W. (2003), “Why Has US Inflation Become Harder to Forecast?”, *Journal of Money, Credit and Banking*, Vol. 39, pp. 3-33.
- [24] Moser, G., Rumler, F. & Scharler, J. (2007), “Forecasting Austrian inflation”, *Economic Modelling*, Vol. 24, Issue 3, May 2007, pp. 470-480.
- [24] Rose, D.E. (1977), “Forecasting aggregates of independent ARIMA processes”, *Journal of Econometrics* Vol. 5, pp.323-345.
- [24] Stock, J. H. and Watson, M. W. (2002), “Macroeconomic forecasting using Diffusion Indexes ”, *Journal of Business and Economic Statistics*, Vol. 20, No.2, pp. 147-162.
- [24] Stock, J. H. and Watson, M. W. (2003), “Macroeconomic forecasting in the euro area: Country specific versus area-wide information”, *European Economic Review*, Vol. 47, pp. 1-18.
- [24] Tiao, G. C. and Guttman, I. (1980), “Forecasting contemporaneous aggregates of multiple time series”, *Journal of Econometrics*, Vol. 12, pp. 219-230.
- [24] Zellner, A. and Tobias, J. (2000), “A note on aggregation, disaggregation and forecasting performance”, *Journal of Forecasting* Vol. 19, pp. 457-469.



**Table 1: List of Items in each Aggregate**

HICP Inflation Aggregates		
5 Item List	12 Item List	32 Item List
Processed Food Unprocessed Food Non-Energy Goods Energy Services	Food + beverages Alcohol + Tobacco Clothing + Footwear Housing Furnishing Health Transport Communications Recreation + culture Education Restaurants + hotels Miscellaneous	Food Non-alcoholic beverages Alcoholic beverages Tobacco Clothing Footwear Rents for Housing Housing Maintenance Water supply + misc. services Electricity, gas and fuels Furniture and furnishings Textiles Appliances Ware and Utensils Tools and Equipment Routine Maintenance Health Purchase of vehicles Vehicles operation Transport services Postal services Telephone and telefax Electronic Equipment Other durables for recreation Recreation, garden and pets Recreation services Reading and stationary Holidays Education Catering services Accommodation services Miscellaneous
PCE Inflation Aggregates		
3 Item List	13 Item List	50 Item List
Durables Non-Durables Services	Motor vehicles and parts Durable household equipment Rec. goods and vehicles Other durable goods Food and bev off-premises Clothing and footwear Gas and other energy goods Other nondurable goods Housing and utilities Health care Transportation services Recreation services Food service + accomm Financial services Other services	New motor vehicles Used motor vehicles Vehicle parts Furniture and furnishings Household appliances Household utensils Equipment for house and garden Video, audio and IT equipment Sporting equipment Sports and recreational vehicles Recreational books Musical instruments Other durable goods Food+ non-alc. bev. off-premises Alcoholic beverages off-premises Food produced + consumed on farm Garments Other clothes and footwear Gas + other energy goods Pharmaceutical + medical products Recreational items Household supplies Personal care products Tobacco Newspapers and magazines Exp. abroad by US residents Less remittances to nonresidents Housing Household utilities Outpatient services Hospital and nursing homes Motor vehicle services Public transportation Parks, theaters,museums etc Audiovisual + IT services Gambling Other recreational services Food services Accommodations Financial services Insurance Communication Education services Professional and other services Personal care and clothing services Social serv + religious activities Household maintenance Foreign travel by US Residents Less Exp in US by nonresidents Nonprofit Institution Exp.

Note: Some categories have been abbreviation. The list for the 169-item breakdown is available upon request.

**Table 2: Forecast Errors for Standard AR Models**

United States						
Quarter	AO	Aggregate	3 Items	15 Items	50 Items	164 Items
1	0.35	0.74*	0.66*	0.69*	0.67*	0.67*
2	0.73	1.02	0.86**	0.81**	0.84**	0.86**
3	1.16	1.08	0.91**	0.85**	0.90**	0.91**
4	1.63	1.22	1.01	0.94**	1.01	1.02
5	1.69	1.28	1.07	0.95**	1.08	1.08
6	1.56	1.41	1.20	1.09	1.29	1.29
7	1.48	1.53	1.32	1.26	1.50	1.52
8	1.32	1.62	1.49	1.50	1.79	1.84
Euro Area						
Month	AO	Aggregate	5 Items	12 Items	32 Items	
1	0.07	0.92*	0.76**	0.78**	0.75**	
2	0.18	0.92*	0.67**	0.71**	0.62**	
3	0.33	0.99	0.62**	0.69**	0.58**	
4	0.49	1.00	0.57**	0.65**	0.56**	
5	0.68	0.98	0.56**	0.64**	0.56**	
6	0.83	0.96	0.54**	0.60**	0.52**	
7	0.99	0.91*	0.54*	0.57**	0.50**	
8	1.18	0.87*	0.56*	0.54*	0.49*	
9	1.34	0.81*	0.57*	0.54*	0.50*	
10	1.51	0.75*	0.57*	0.52*	0.48*	
11	1.67	0.68*	0.57*	0.48*	0.47*	
12	1.84	0.64*	0.57*	0.47*	0.46*	

Note: The table presents ratios of RMSE for each model relative to the benchmark. A value less than one indicates that the model has more accurate forecasts than the benchmark. The RMSE of the Atkeson-Ohanian benchmark is in the first column. Asterisks denote rejection of the null hypothesis of equal predictive accuracy between each model and the AO at 5% (\*\*) and 10% (\*) significance levels.

**Table 3: Forecast Errors for FAAR Model**

United States						
Quarter	AO	Aggregate	3 Items	15 Items	50 Items	164 Items
1	0.35	0.66*	0.63*	0.66*	0.64*	0.60*
2	0.73	0.85**	0.79**	0.76**	0.75**	0.72**
3	1.16	0.93**	0.87**	0.79**	0.78**	0.74**
4	1.63	1.09	0.96**	0.86**	0.85**	0.81**
5	1.69	1.16	0.98*	0.83**	0.84**	0.77**
6	1.56	1.32	1.07	0.92*	0.95*	0.87*
7	1.48	1.48	1.19	1.03	1.09	1.02
8	1.32	1.59	1.33	1.18	1.27	1.23
Euro Area						
Month	AO	Aggregate	5 Items	12 Items	32 Items	
1	0.07	0.94	0.78**	0.80**	0.77**	
2	0.18	0.95	0.68**	0.73**	0.63**	
3	0.33	1.00	0.63**	0.70**	0.58**	
4	0.49	1.00	0.58**	0.65**	0.57**	
5	0.68	0.97	0.56**	0.64**	0.56**	
6	0.83	0.95*	0.54**	0.59**	0.52**	
7	0.99	0.91*	0.54**	0.57**	0.50**	
8	1.18	0.87*	0.56*	0.54**	0.50**	
9	1.34	0.82*	0.57*	0.55*	0.50*	
10	1.51	0.75*	0.57*	0.52*	0.48*	
11	1.67	0.69*	0.57*	0.49*	0.47*	
12	1.84	0.64*	0.57*	0.47*	0.46*	

See Notes for Table 2 above.

**Table 4: Change in RMSE by Including Factor**

United States					
Quarter	Aggregate	3-item	15-item	50-item	169-item
1	0.89**	0.95**	0.96**	0.95**	0.90**
2	0.83**	0.92**	0.93**	0.89**	0.83**
3	0.86**	0.95*	0.93**	0.87**	0.81**
4	0.90**	0.95**	0.92**	0.84**	0.79**
5	0.91**	0.91**	0.88**	0.78**	0.71**
6	0.94*	0.89**	0.84**	0.74**	0.67**
7	0.97	0.90	0.82**	0.73**	0.67**
8	0.98	0.89	0.79**	0.71**	0.67**
Euro Area					
Month	Aggregate	5 Items	12 Items	32 Items	
1	1.02	1.02	1.02	1.03	
2	1.03	1.02	1.03	1.03	
3	1.01	1.02	1.01	1.01	
4	1.00	1.01	1.01	1.01	
5	0.99	1.01	1.00	1.00	
6	0.99	1.00	1.00	1.00	
7	1.00	1.00	1.00	1.00	
8	1.00	1.01	1.00	1.00	
9	1.01	1.00	1.00	1.00	
10	1.01	1.00	1.00	1.00	
11	1.01	1.01	1.01	1.01	
12	1.01	1.01	1.01	1.01	

Note: The table presents ratios of RMSE for AR models which include a factor to those that don't. It's a measure of the change in forecast accuracy as a result of including the factor in the model. A value less one means the model with the factor more accurate forecasts. Star superscripts have same meaning as before.

**Table 5: Commonality within Datasets**

PCE	Aggregate	3-item	15-item	50-item	169-item
$R^2$	0.85	0.66	0.50	0.37	0.30
Ave. Corr.	n/a	0.73	0.61	0.47	0.39
HICP	Aggregate	5-item	12-item	32-item	
$R^2$	0.37	0.21	0.18	0.21	
Ave. Corr.	n/a	0.16	0.12	0.11	

Note: The individual inflation rates are regressed on the factor only.  $R^2$  is the average for level of aggregation. The second row is average correlation between the inflation rates.

**Table 6: Forecast Errors for BVAR Model**

United States					
Quarter	AO	3-item	15-item	50-item	169-item
1	0.35	0.50**	0.51**	0.50**	0.50**
2	0.73	0.71**	0.67**	0.70**	0.69**
3	1.16	0.85**	0.77**	0.82**	0.81**
4	1.63	0.99*	0.85**	0.93**	0.92**
5	1.69	1.05	0.83**	0.96**	0.93**
6	1.56	1.13	0.85**	1.06	1.00
7	1.48	1.19	0.87**	1.14	1.09
8	1.32	1.31	0.93	1.27	1.23
Euro Area					
Month	AO	5 Items	12 Items	32 Items	
1	0.07	0.67**	0.75**	0.81**	
2	0.18	0.55**	0.58**	0.61**	
3	0.33	0.55**	0.56**	0.57**	
4	0.49	0.54**	0.55**	0.57**	
5	0.68	0.55**	0.55**	0.58**	
6	0.83	0.56**	0.56**	0.59**	
7	0.99	0.60**	0.62**	0.65**	
8	1.18	0.62*	0.65**	0.70*	
9	1.34	0.65*	0.68**	0.73*	
10	1.51	0.67*	0.69*	0.75*	
11	1.67	0.69*	0.71*	0.77**	
12	1.84	0.72*	0.72*	0.80**	

Note: The table presents the performance of the BVAR. As this is a multivariate model, there are no results to report for the aggregate alone. Star superscripts have same meaning as before.

**Table 7: US Time-Varying AR Model Based on 15 Items**

Quarter	$P_{t+h} - P_t$		
	AO	TV-AR/AO	TV-AR/BVAR
1	0.35	0.78	0.88
2	0.73	0.75	0.87
3	1.16	0.74	0.87
4	1.63	0.73	0.89
5	1.69	0.69	0.90
6	1.56	0.72	0.94
7	1.48	0.79	1.03
8	1.32	0.88	1.11

Note: The second results column shows the RMSE of the 15-item TV-AR while the third column is the ratio of the RMSE of the 15-item TV-AR to the 15-item BVAR.

## Appendix 1: Alternative Data Transformation

As a robustness check, we perform the forecasting exercise for a different price transformation, the  $h$ -level change in log prices  $p_{t+h} - p_t$ . This is analyzed only for the US dataset, given that the seasonal issues with the EA data makes it difficult to look at alternative data transformations beyond the year-on-year inflation rate, which is analyzed in the main body of the paper. At a given horizon  $h$ , the AR and FAAR forecasting equations are exactly those of *eq.(3)* and *eq.(4)* respectively. Forecasts with the BVAR model are computed exactly as before, but the log-level of price at time  $t$  is then subtracted by the forecast of  $p_{t+h}$  in order to recover the  $h$ -level change of log-prices.

Appendix Table A1 presents the results for the standard AR model. The aggregate does not perform well, as it beats the benchmark only for the one-period forecast. The 3-item and 15-item forecasts are both more accurate than the benchmark up to five quarters. The results are presented graphically in Figure 9. The pattern mimics the year-on-year results, where the 3-item and 15-item forecasts are far better than the benchmark. Table A2 presents the results with the factor included. In further agreement with the year-on-year results, the aggregate still has the worst average performance and the 169-item model now has the most accurate forecasts. Figure 10 plots the results and it demonstrates how quickly the performance of the aggregate deteriorates over the forecast horizon from a strong starting position. Table A3 shows that the BVAR models also improve significantly on the AR specification, especially in relation to the long-range forecasts. The performance of the BVAR models is graphed in Figure 11. For the multistep forecasts in the previous section, the 15-item BVAR is the only breakdown which is clearly better than its factor comparator. For the forecasts considered here, the 3-item BVAR also outperforms the 3-item factor model due to good performance at the short horizons. Thus, when we compare the two model types averaged by all their forecasts, the BVAR is more accurate than the factor model by approximately 7%. As before, the best BVAR model is still based on 15 items. Overall, these results strongly mirror those of the year-on-year specification. In this exercise, the aggregate model never provides the best forecasts and often provides the worst. The key properties of the data affect the disaggregate forecasts in the same way irrespective of the data transformation.

**Table A1: Errors for AR model Forecasts of  $P_{t+h} - P_t$** 

Quarter	United States					
	AO	Aggregate	3 Items	15 Items	50 Items	164 Items
1	3.09	0.90	0.92	0.92	0.90	0.93
2	2.27	1.05	0.96	0.92	0.93	0.96
3	1.82	1.16	0.98	0.96	0.99	1.04
4	1.63	1.17	0.98	0.99	1.06	1.09
5	1.42	1.14	0.99	0.98	1.09	1.15
6	0.98	1.29	1.10	1.15	1.35	1.48
7	0.77	1.45	1.23	1.37	1.65	1.85
8	0.62	1.54	1.35	1.65	2.02	2.35

Note: The table presents ratios of RMSE for each model relative to the benchmark. Only applies to US data.

**Table A2: Errors for FAAR Model Forecasts of  $P_{t+h} - P_t$** 

Quarter	United States					
	AO	Aggregate	3 Items	15 Items	50 Items	164 Items
1	3.09	0.85	0.93	0.91	0.88	0.89
2	2.27	0.97	0.96	0.90	0.87	0.84
3	1.82	1.09	1.00	0.92	0.90	0.85
4	1.63	1.11	1.01	0.93	0.91	0.84
5	1.42	1.09	1.01	0.88	0.88	0.81
6	0.98	1.28	1.09	0.91	0.94	0.86
7	0.77	1.46	1.19	1.00	1.05	0.97
8	0.62	1.54	1.27	1.09	1.17	1.10

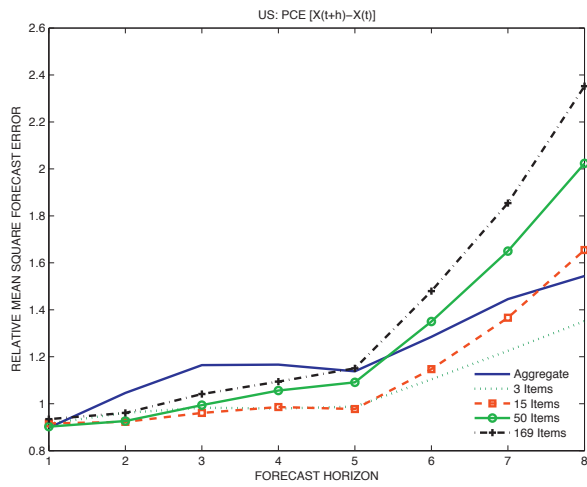
Note: The table presents ratios of RMSE for each model relative to the benchmark. Only applies to US data.

**Table A3: Errors for BVAR Model Forecasts of  $P_{t+h} - P_t$** 

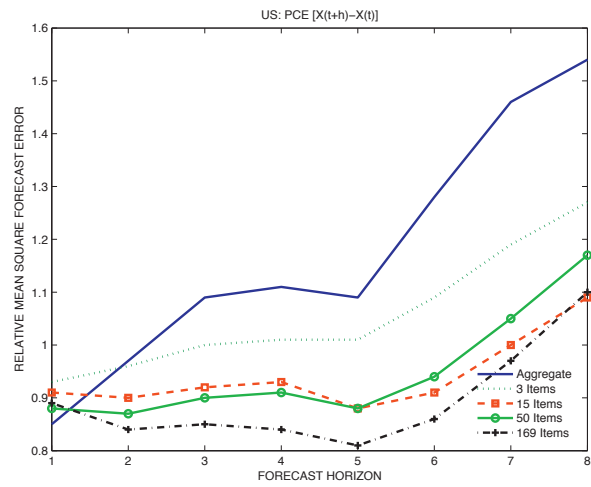
Quarter	United States				
	AO	3-item	15-item	50-item	169-item
1	3.09	0.84	0.89	0.90	0.91
2	2.27	0.81	0.86	0.92	0.92
3	1.82	0.81	0.86	0.94	0.95
4	1.63	0.80	0.82	0.92	0.94
5	1.42	0.78	0.76	0.91	0.93
6	0.98	0.88	0.76	0.92	0.92
7	0.77	0.97	0.76	0.93	0.93
8	0.62	1.10	0.79	0.96	0.93

Note: The table presents the performance of the BVAR. As this is a multivariate model, there are no results to report for the aggregate alone.

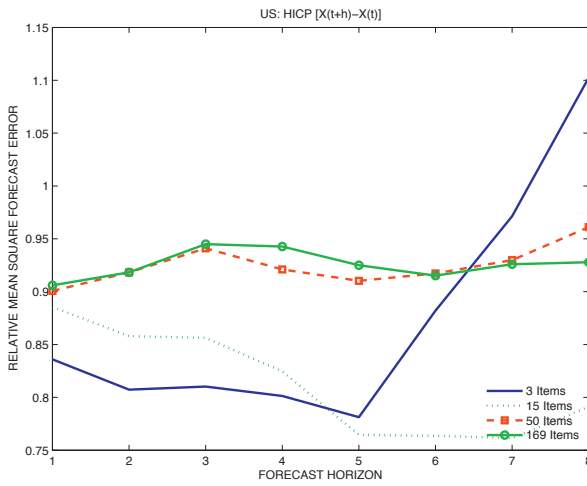
**Figure A1: RMSFE of AR Model  
versus AO (US)**



**Figure A2: RMSFE of FAAR Model  
versus AO (US)**



**Figure A3: RMSFE of BVAR Model  
versus AO (US)**



**Figure 9: RMSFE of the AR, FAAR, BVAR  
and TV-AR Models versus AO (US - 15 items)**

